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Elahi et al.

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(54) **VARIABLE GUIDE BEARING**

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F03B 15/00	(2006.01)
G01B 7/14	(2006.01)
F03B 13/00	(2006.01)
H02K 5/16	(2006.01)

(52) **U.S. Cl.**
CPC ***F03B 15/00*** (2013.01); ***F03B 11/06*** (2013.01); ***F03B 11/063*** (2013.01); ***F03B 13/00*** (2013.01); ***G01B 7/14*** (2013.01); *H02K 5/16* (2013.01)

(58) **Field of Classification Search**
CPC F03B 11/06; F03B 11/063
See application file for complete search history.

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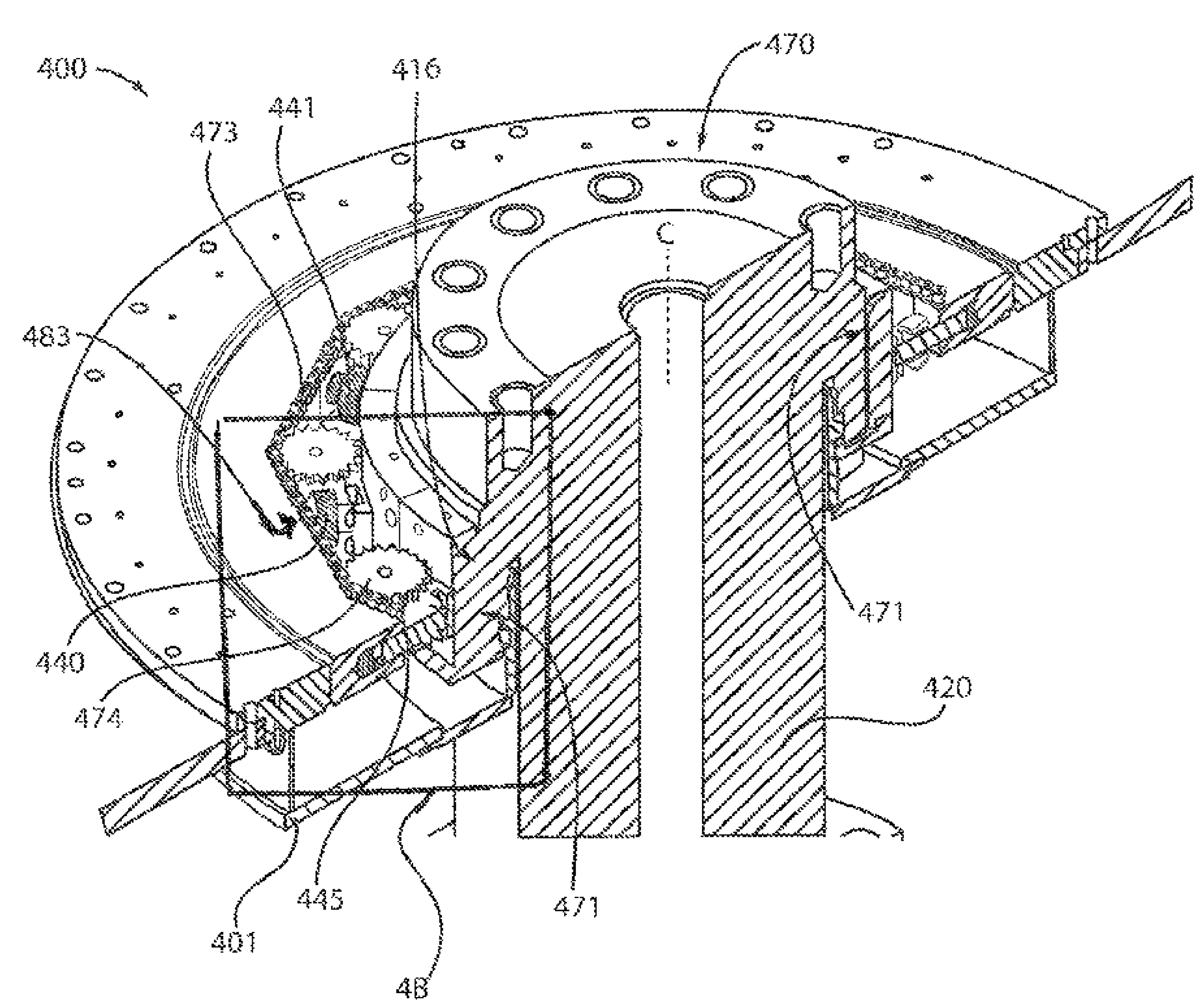
(57) **ABSTRACT**

A guide bearing system including a pad adjuster to traverse at least one bearing in a direction to adjust a radial clearance. The system can further include a sensor for measuring deviations in the radial clearance. In some embodiments, the guide bearing system includes a controller that receives a distance signal from the sensor measuring the radial clearance and signals the pad adjuster to traverse the at least one bearing to compensate for the deviations in the radial clearance.

15 Claims, 10 Drawing Sheets

1000b



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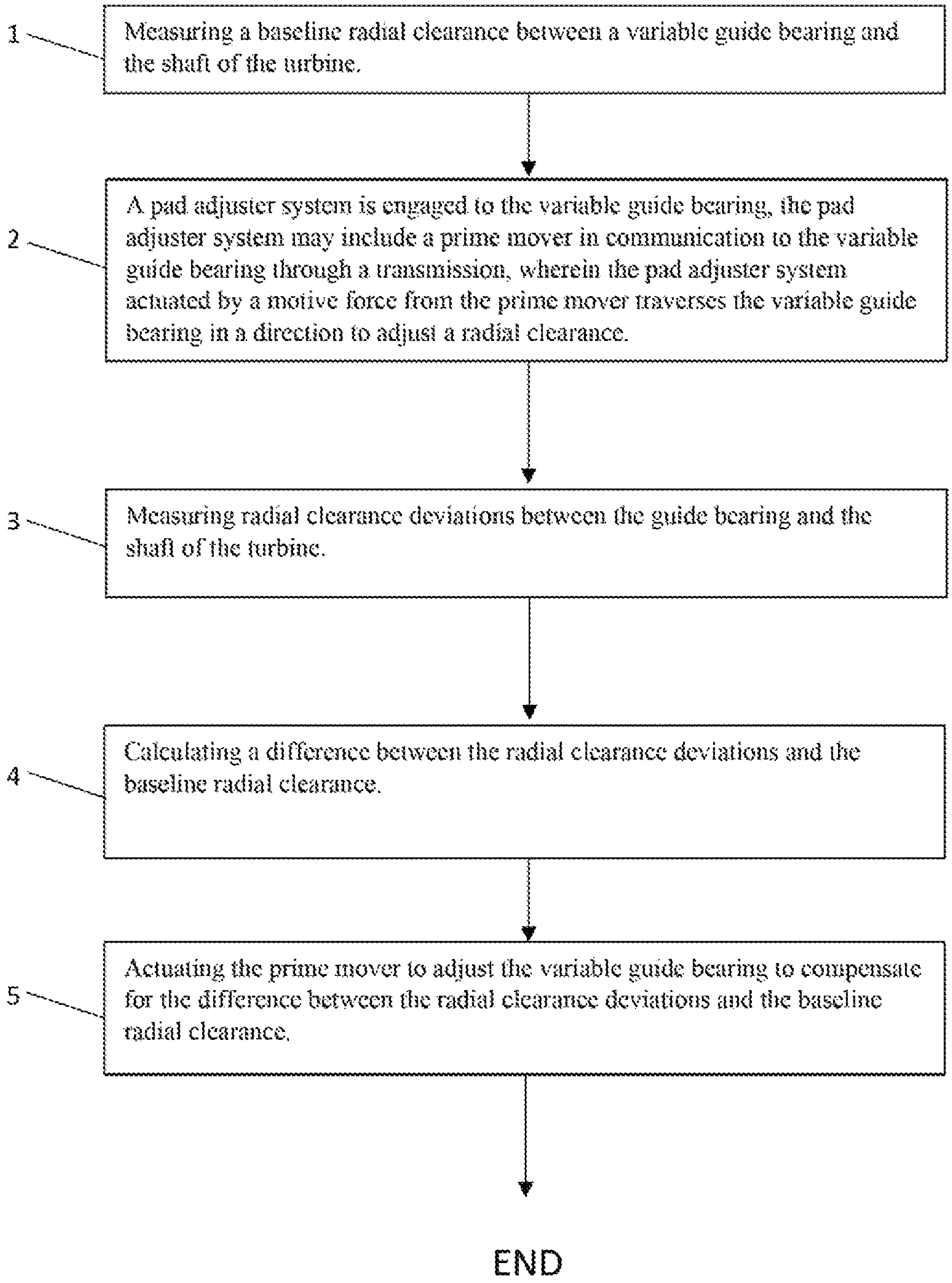
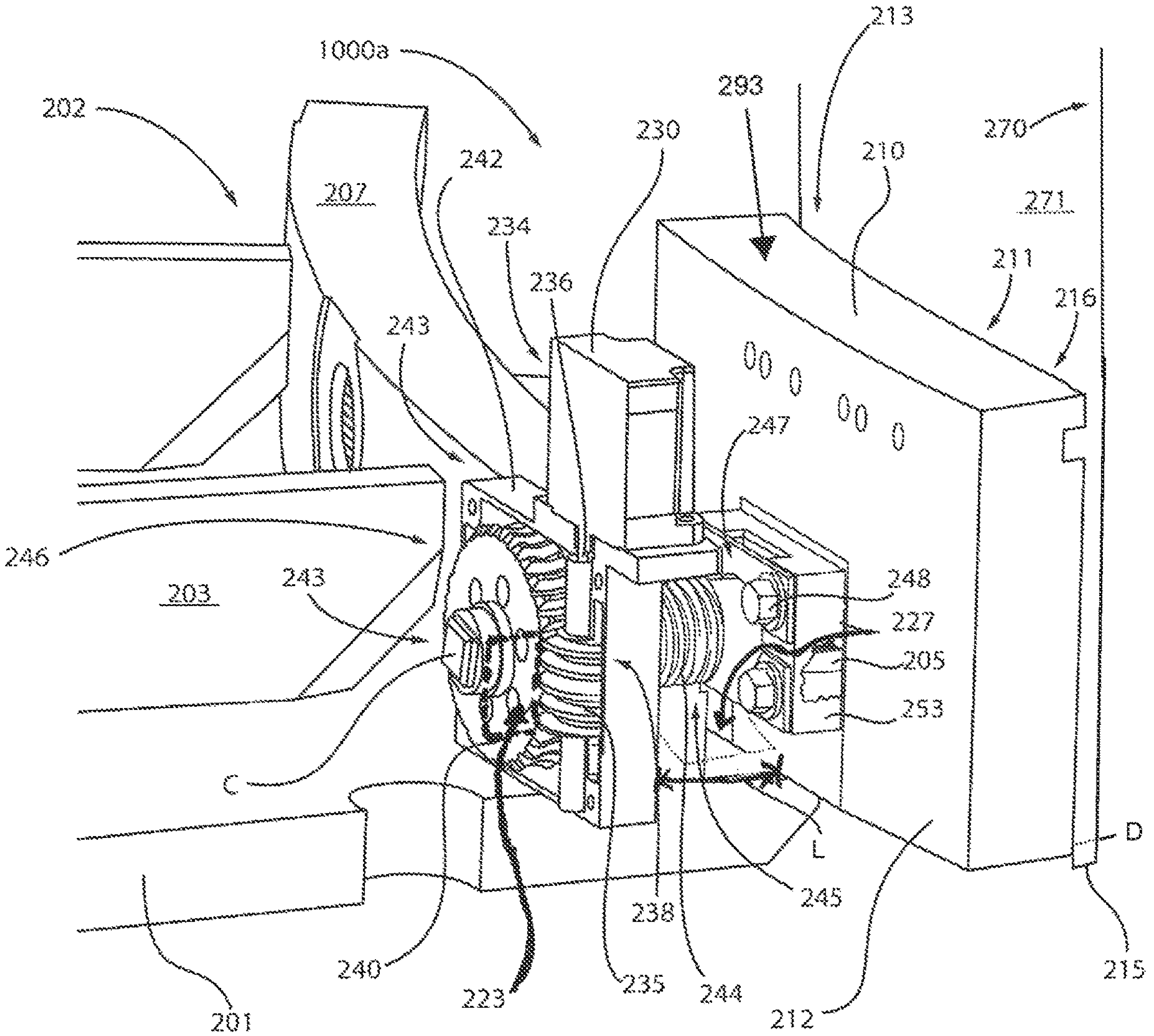

1
Measuring a baseline radial clearance between a variable guide bearing and the shaft of the turbine.
2
A pad adjuster system is engaged to the variable guide bearing, the pad adjuster system may include a prime mover in communication to the variable guide bearing through a transmission, wherein the pad adjuster system actuated by a motive force from the prime mover traverses the variable guide bearing in a direction to adjust a radial clearance.
3
Measuring radial clearance deviations between the guide bearing and the shaft of the turbine.
4
Calculating a difference between the radial clearance deviations and the baseline radial clearance.
5
Actuating the prime mover to adjust the variable guide bearing to compensate for the difference between the radial clearance deviations and the baseline radial clearance.
END

FIG. 1



1000a
202
207
242
234
236
230
293
213
210
270
271
211
216
243
247
246
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D
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240
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212
215
201

FIG. 2

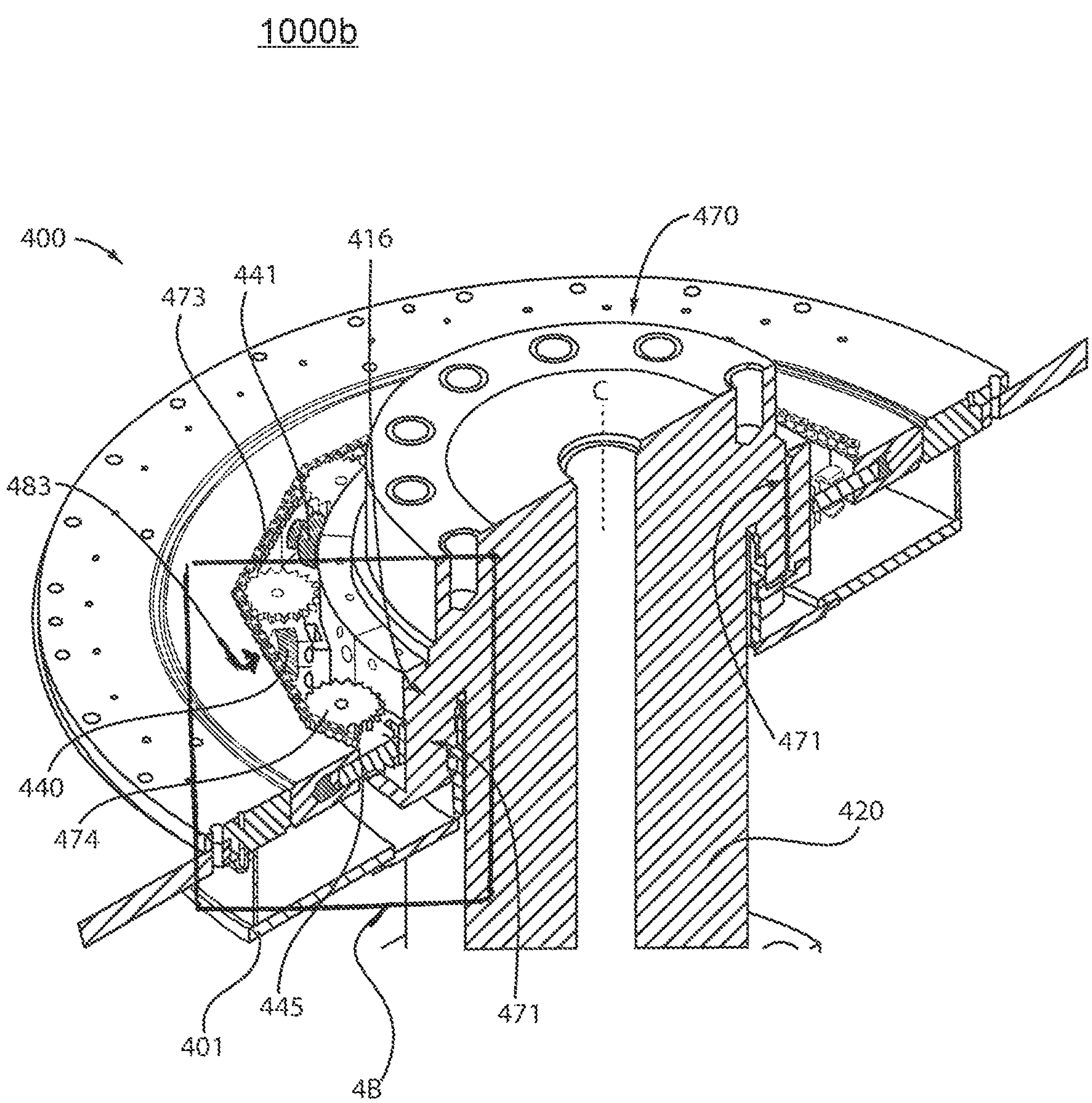

FIG. 3A

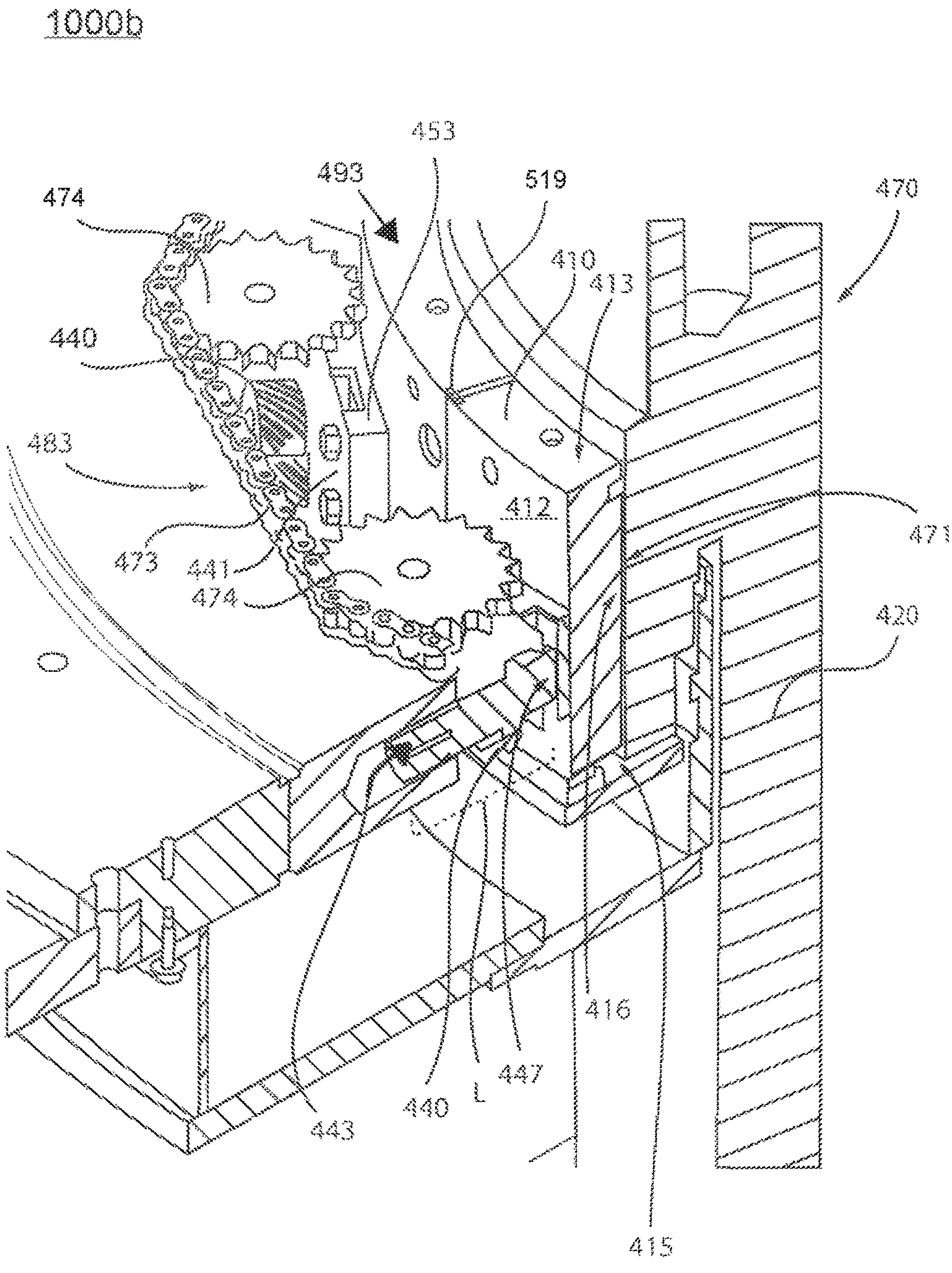
1000b
453
493
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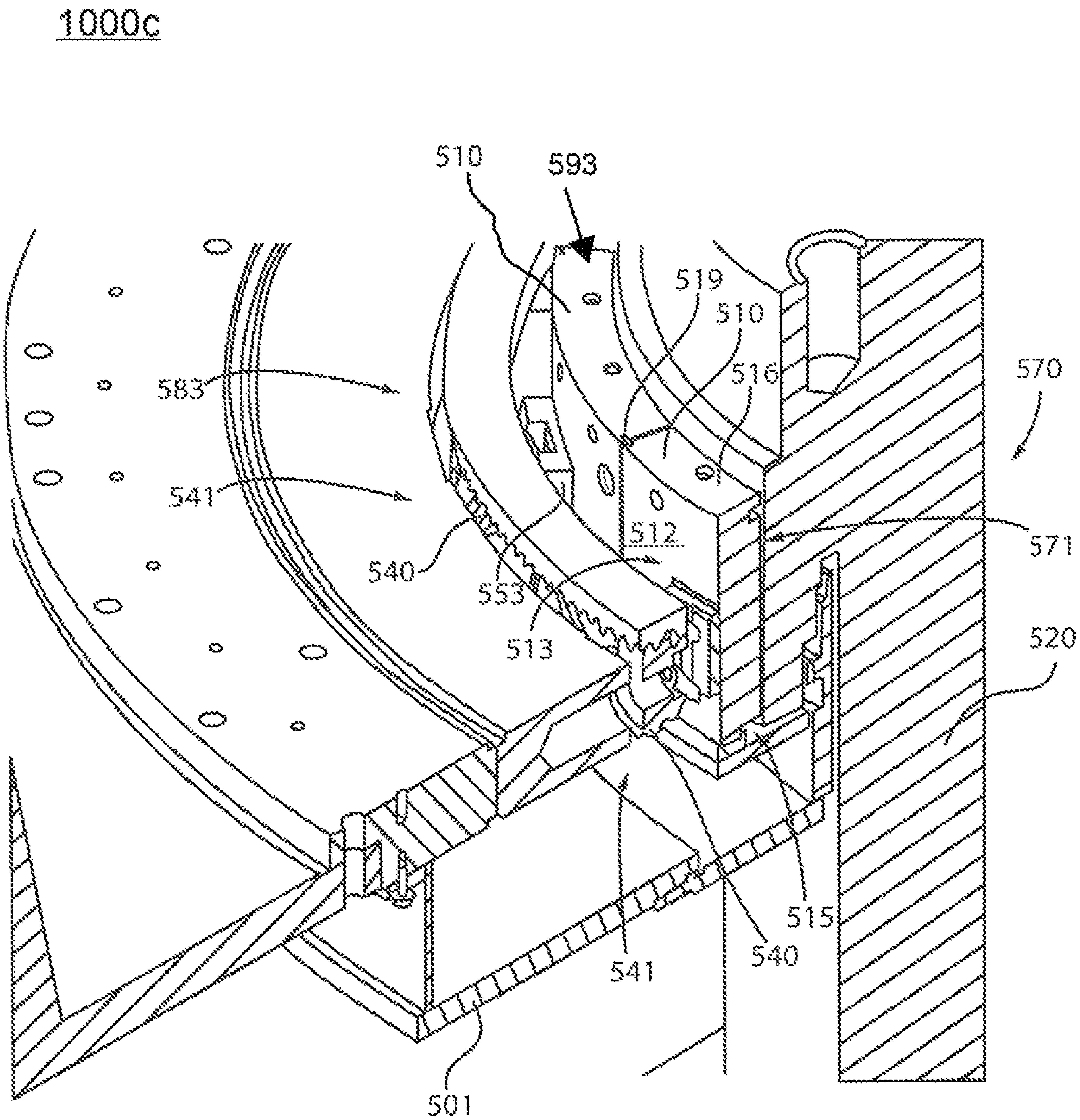
FIG. 3B


1000c
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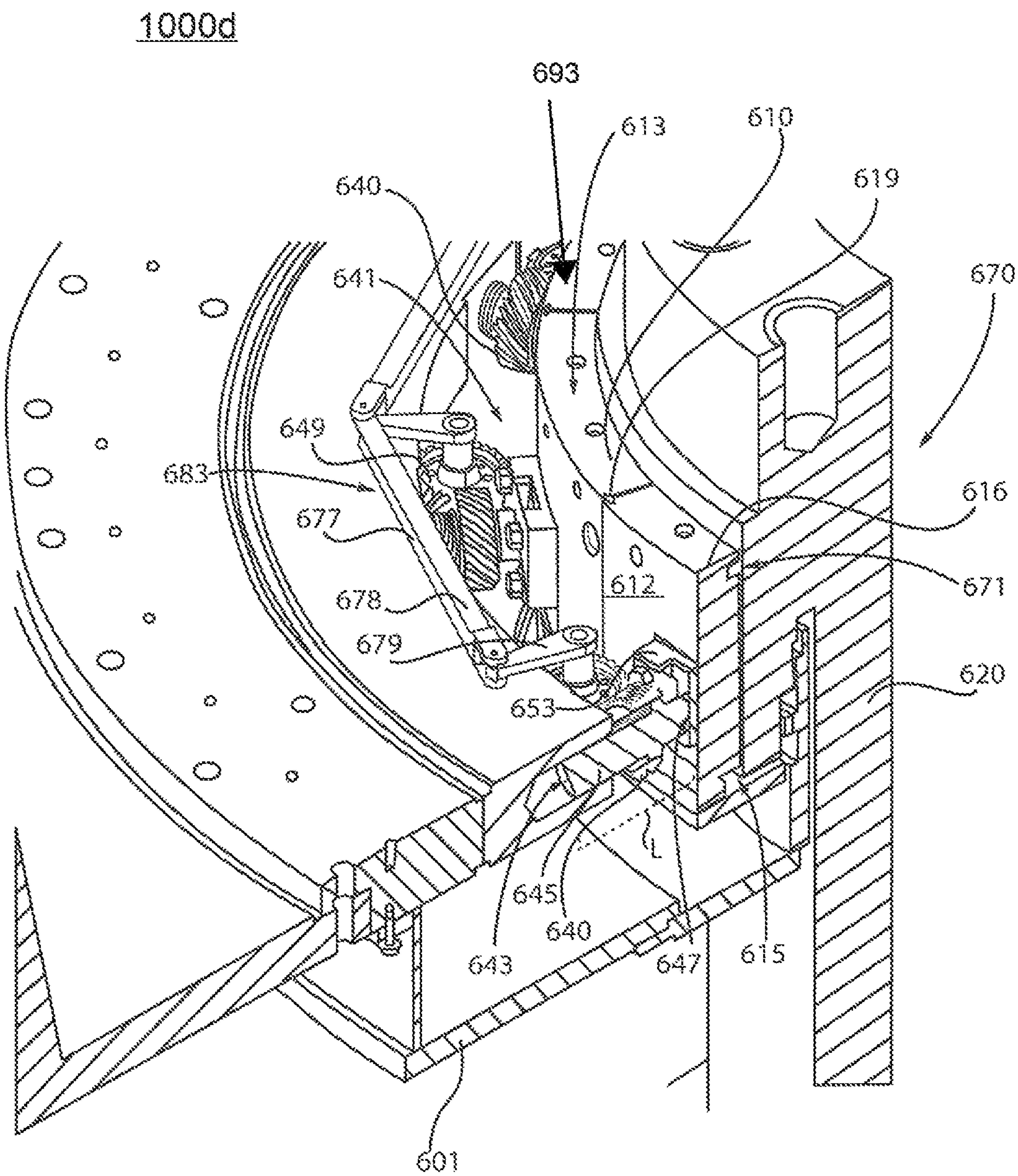
501

FIG. 4


1000d
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645
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615
601

FIG.5

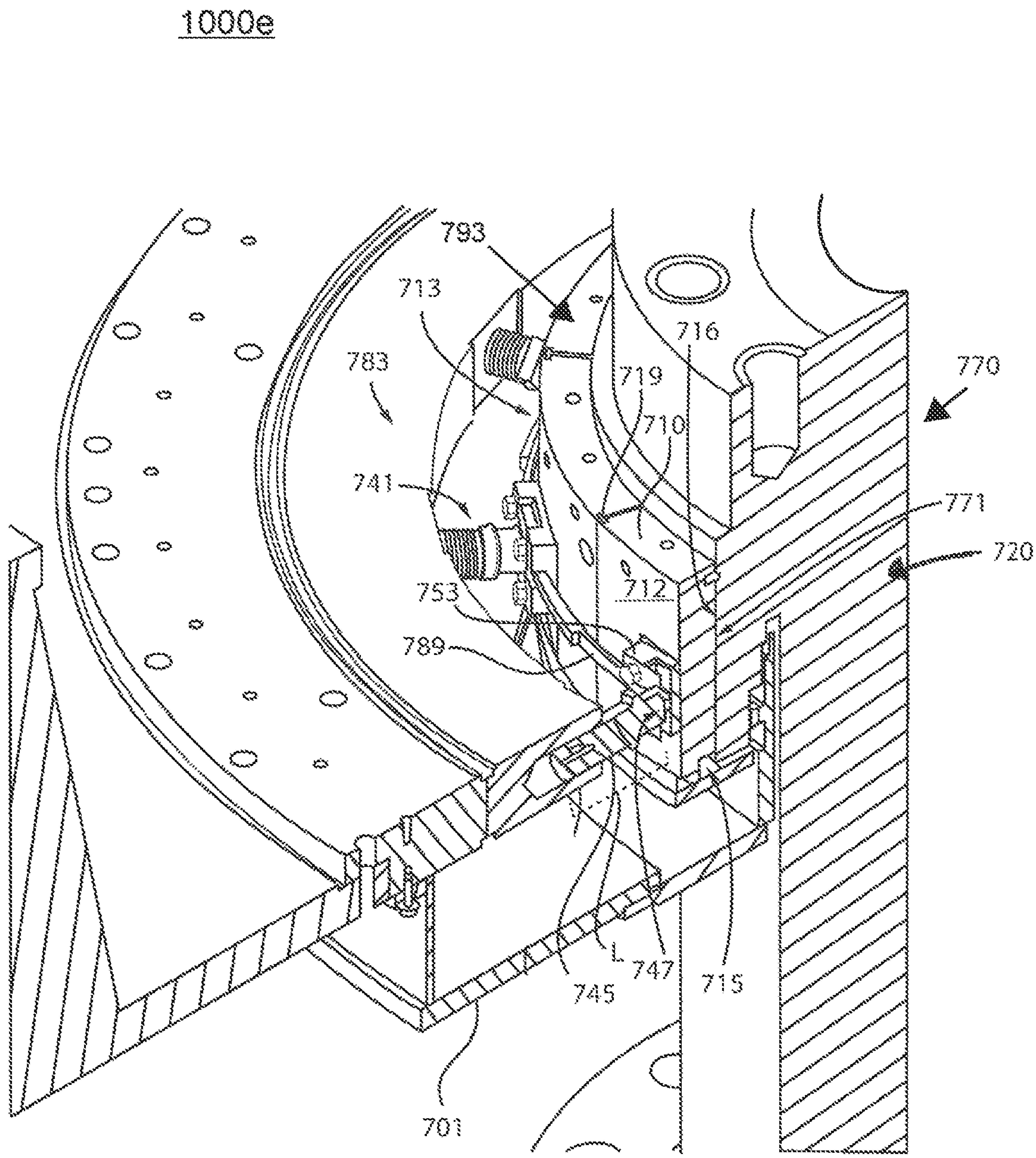
1000e
793
713
783
741
753
789
716
719
710
770
771
720
712
745
747
715
701
L

FIG. 6

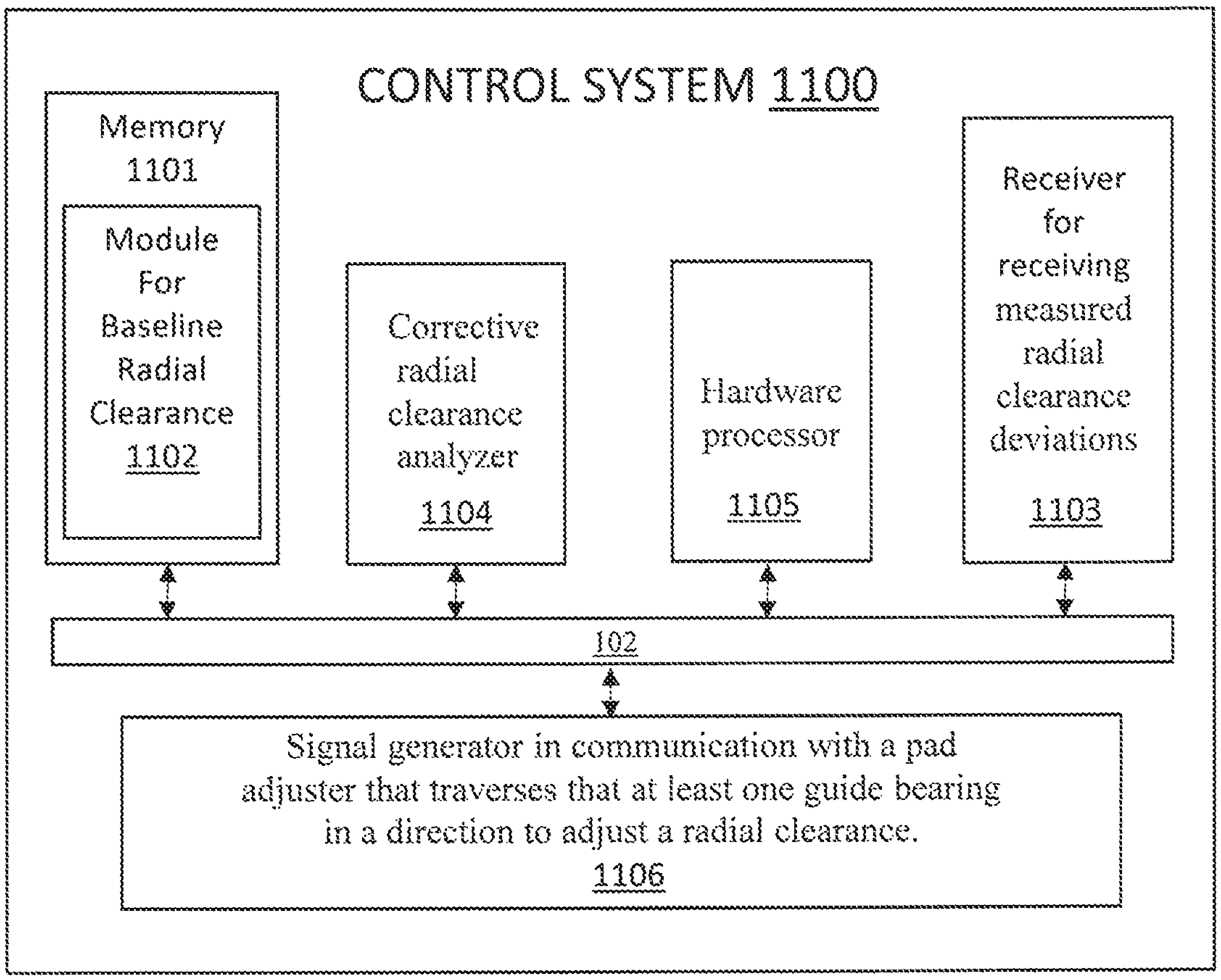
CONTROL SYSTEM 1100
Memory 1101
Module For Baseline Radial Clearance 1102
Corrective radial clearance analyzer 1104
Hardware processor 1105
Receiver for receiving measured radial clearance deviations 1103
102
Signal generator in communication with a pad adjuster that traverses that at least one guide bearing in a direction to adjust a radial clearance.
1106

FIG. 7

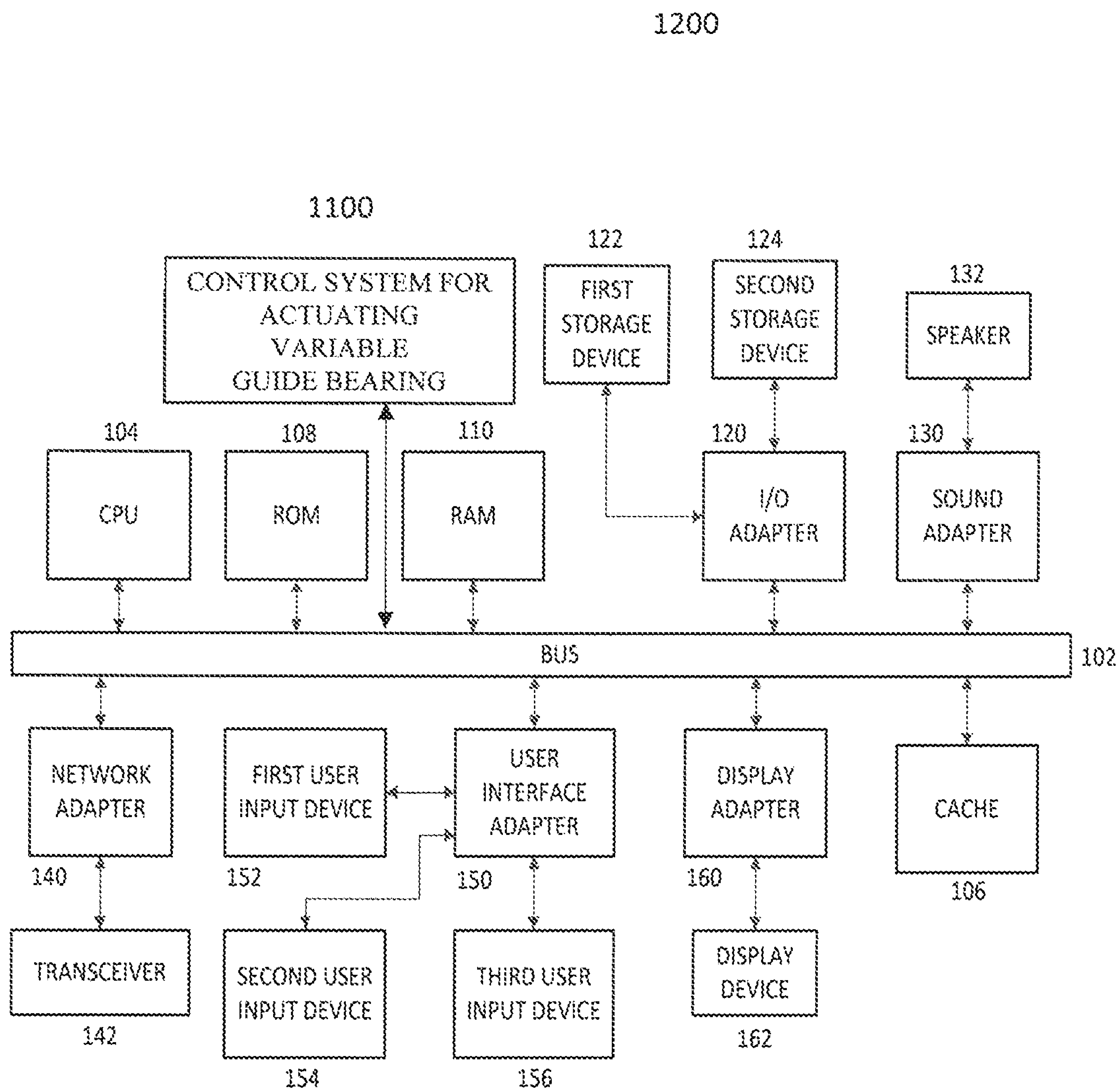
1200
1100
CONTROL SYSTEM FOR ACTUATING VARIABLE GUIDE BEARING
122
FIRST STORAGE DEVICE
124
SECOND STORAGE DEVICE
132
SPEAKER
104
CPU
108
ROM
110
RAM
120
I/O ADAPTER
130
SOUND ADAPTER
BUS
102
NETWORK ADAPTER
140
FIRST USER INPUT DEVICE
152
USER INTERFACE ADAPTER
150
DISPLAY ADAPTER
160
CACHE
106
TRANSCEIVER
142
SECOND USER INPUT DEVICE
154
THIRD USER INPUT DEVICE
156
DISPLAY DEVICE
162

FIG. 8

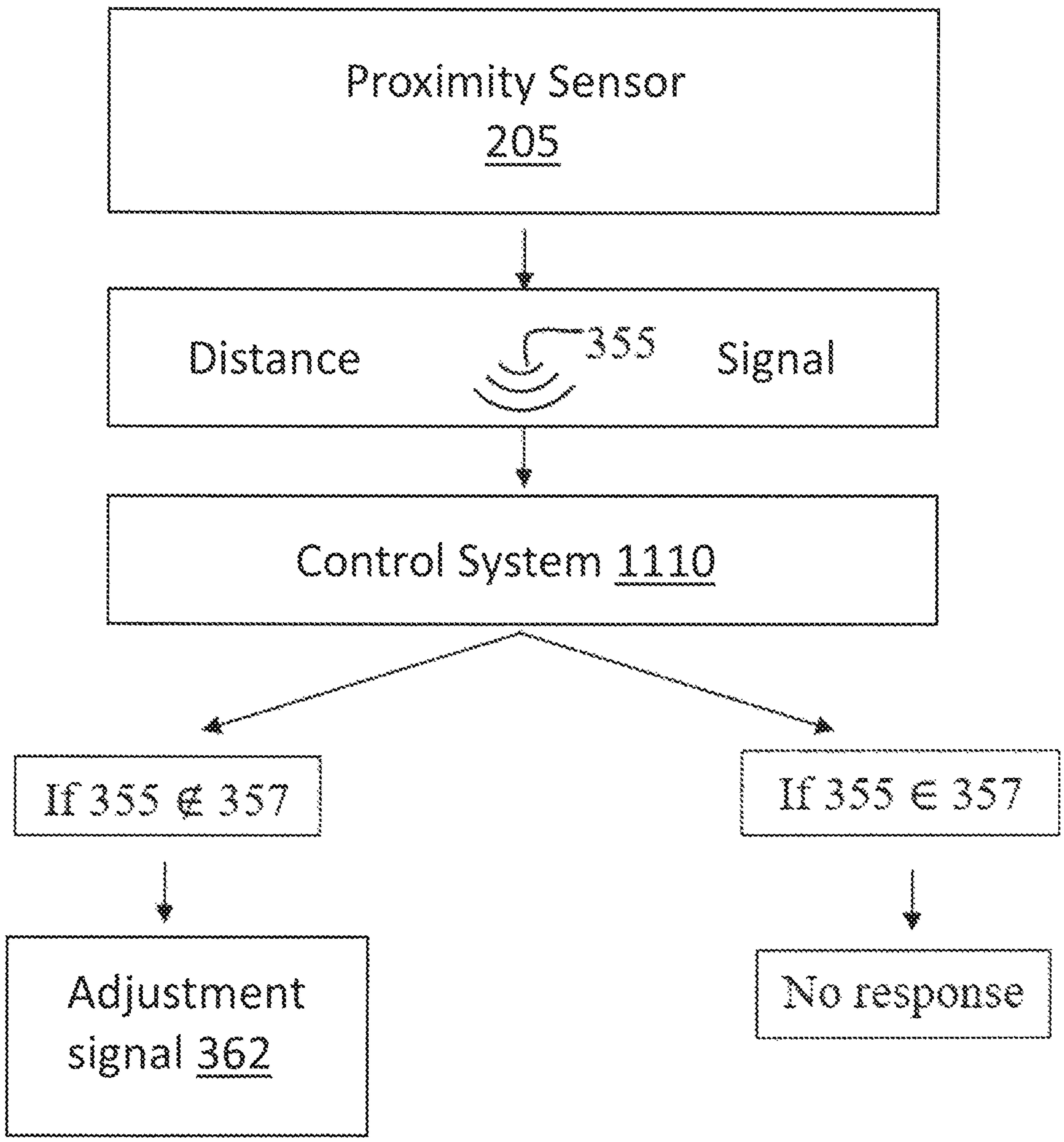
Proximity Sensor
205
Distance
355
Signal
Control System 1110
If 355 ∉ 357
If 355 ∈ 357
Adjustment signal 362
No response

FIG. 9

VARIABLE GUIDE BEARING

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of and priority to U.S. Provisional Patent Application No. 62/751,033, filed Oct. 26, 2018, the entire contents of which are hereby incorporated herein by reference.

BACKGROUND OF THE INVENTION

Technical Field

The present disclosure relates generally to hydrodynamic bearings with discrete guide bearing pads, and more particularly to hydrodynamic bearings used in the hydroelectric industry.

Related Art

Hydroelectric turbine-generator assemblies produce electrical energy using a renewable resource and without combusting fossil fuels. A turbine converts kinetic energy from flowing water into mechanical energy of rotation. A shaft connected to the turbine transmits the mechanical energy to a rotor assembly in a generator. The generator then converts the mechanical energy into electrical energy.

A generator may include a generator housing that encompasses the stator assembly and the nested rotor assembly. The stationary stator assembly may include multiple coils. The rotor assembly may include multiple magnets configured to rotate within the stator assembly relative to the stator coils. A small air gap separates the rotor assembly from the stator assembly. The shaft transmits mechanical energy from the turbine to rotate the rotor assembly. As the rotor assembly spins, the movement of the magnets past the stationary stator coils induces an electric current in the coils. The generated electricity may then be transferred for further processing, storage, or distribution.

Hydroelectric turbine assemblies tend to have hydrodynamic guide bearings disposed adjacent to the shaft, below and/or above the generator. A thrust bearing may also be disposed above the generator. A guide bearing may include multiple discrete guide bearing pads (or "shoes") configured to reduce friction, facilitate rotational shaft movement during operation, resist lateral forces during fault events, and to center the shaft in the shaft housing. The guide bearing pads may be disposed annularly within a shaft housing. When the shaft is present, the guide bearing pads define a radial guide bearing clearance between the guide bearing pads and the shaft. A shaft seal may be disposed below and above the guide bearing pads to contain hydrodynamic fluid (typically oil or water). The fluid fills spaces between the shaft, shaft housing, and shaft seals, including the radial guide bearing clearance. Ideally, the shaft spins against a film of fluid annularly disposed between the guide bearing pads and the rotating shaft. In operation, this fluid film is generally highly pressurized by the relative motion of the shaft to the pads in order to resist normal and fault forces and to keep the shaft centered. In practice however, the width of the radial guide bearing clearance can differ significantly depending on the bearing system's ambient temperatures.

SUMMARY

In accordance with some aspects of the present disclosure, methods, structures and computer program products are described herein that can mitigate the effects of variations in the radial guide bearing clearance between the guide bearing pads and the shaft of a turbine assembly, such as a hydroelectric turbine assembly.

In some embodiments, the problem of shaft vibrations due to distance variations in a radial guide bearing clearance in a rotating machine having a hydrodynamic bearing is mitigated by a system configured to monitor the radial clearance and to adjust a position of one or more guide bearing pads relative to the shaft while the rotating machine is active.

In one aspect, a method is provided for maintaining a radial clearance between a variable guide bearing and a shaft of a turbine. In one embodiment, the method may include measuring a baseline radial clearance between at least one guide bearing and the shaft of the turbine. A pad adjuster may be engaged to at least one guide bearing. The pad adjuster may include a prime mover in communication to at least one guide bearing through a transmission, wherein the pad adjuster actuated by a motive force from the prime mover that traverses at least one guide bearing in a direction to adjust a radial clearance. The method may further include measuring radial clearance deviations between the at least one guide bearing and the shaft of the turbine. The method also includes calculating a difference between the radial clearance deviations and the baseline radial clearance. In some embodiments, the method includes actuating the prime mover to adjust the at least one guide bearing to compensate for the difference between the radial clearance deviations and the baseline radial clearance. In some embodiments, the method is a computer implemented method.

In another aspect of the present disclosure, a guide bearing system is provided. In one embodiment, the guide bearing system can include a pad adjuster system to traverse at least one bearing in a direction to adjust a radial clearance. The radial clearance is a dimension between an outermost shaft end of the at least one bearing pad and an outermost perimeter of a shaft assembly. The system can further include a sensor for measuring deviations in the radial clearance. In some embodiments, the guide bearing system includes a controller that receives a distance signal from the sensor measuring the radial clearance and signals the pad adjuster system to traverse the at least one bearing to compensate for the deviations in the radial clearance.

In another embodiment, the guide bearing system may include a gearing system and a pad adjuster mechanically engaged to the gearing system. The pad adjuster may have a pad end distally disposed from the gearing system, wherein the pad end is engaged to a bearing pad. The guide bearing system may further include a prime mover engaging the gearing system such that the prime mover is not co-linear with a radial line disposed on a radial plane defined by the center of rotation of the shaft. A proximity sensor may be configured to detect a distance of the radial clearance between a guide bearing pad and the shaft. The proximity sensor generates a distance signal and transmits the distance signal to a control system. In some embodiments, the control system compares the distance measurement signal to a programmed range, wherein the control system sends an adjustment signal to a prime mover if the distance measurement signal does not match the programmed range. In some embodiments, the prime mover engages a gearing system worm drive engaging a worm wheel and configured to turn a worm wheel. The worm wheel may be configured to turn the pad adjuster. The pad adjuster can be configured to move the guide bearing pad along a radial plane defined by the center of rotation of the shaft.

An advantage of the exemplary system may be that the radial guide bearing clearance may be continuously monitored and adjusted in response to a thermally expanding shaft, thereby maintaining an optimal radial guide bearing clearance during startup and throughout operation of the rotating machine. Furthermore, the radial guide clearance occasionally changes abruptly during operation in response to an upset condition. An upset condition may result from hydraulic disturbances, electrical fault, applying the turbine brakes suddenly, the turbine runner encountering a large piece of debris, or some other unplanned operational event. A further advantage of the exemplary systems that are described herein may be the protection against back driving that may otherwise result from the above described upset conditions.

It has been discovered that by configuring the prime mover to engage a gearing system non-collinearly relative to the real or potential linear movement of the pad adjuster, the exemplary guide bearing adjustment system protects against unexpected back driving that could otherwise damage a bearing adjustment system or result in a loss of shaft guidance. Back driving could also close the gap between rotating and stationary components. Without being bound by theory, it is hypothesized that the non-collinear engagement may provide sufficient counter-force to overcome back driving forces. The guide bearing adjustment bolt may adjust the guide bearing pads radially towards or away from the rotating parts. Without being bounded by theory, it is believed that the order of placement of the worm drive and worm wheel service may protect the prime mover against back-driving from the guide bearing pad. In one embodiment, the prime mover provides a redundant position signal to the control system as a safety check.

In another aspect, a control system is provided that can be employed with the above described methods and structures for maintaining a radial clearance between a variable guide bearing system and a shaft of a turbine. In one embodiment, the control system may include at least one module of memory for storing baseline radial clearance values for a dimension between at least one guide bearing and the shaft of the turbine. The control system may include a receiver for receiving measured radial clearance deviations between at least one guide bearing and the shaft of the turbine. In some embodiments, the control system may further include a corrective radial clearance analyzer that employs a hardware processor for performing a set of instructions for comparing the measured radial clearance deviations to the baseline radial clearance values in providing a corrective radial clearance dimension. The control system further includes at least one signal generator in communication with a pad adjuster that traverses that at least one guide bearing in a direction to adjust a radial clearance.

In yet another aspect, a computer program product is provided that includes a computer readable storage medium having computer readable program code embodied therein for maintaining a radial clearance between a variable guide bearing and a shaft of a turbine. In one embodiment, the computer readable storage medium is non-transitory. The computer readable program code can provide the steps of measuring a baseline radial clearance between at least one guide bearing and the shaft of the turbine. A pad adjuster may be engaged to the at least one guide bearing. The pad adjuster may include a prime mover in communication to the at least one guide bearing through a transmission, wherein the pad adjuster actuated by a motive force from the prime mover traverses that at least one guide bearing in a direction to adjust a radial clearance. The method may further include measuring radial clearance deviations between the at least one guide bearing and the shaft of the turbine, and calculating a difference between the radial clearance deviations and the baseline radial clearance. In some embodiments, the method includes actuating the prime mover to adjust the at least one guide bearing to compensate for the difference between the radial clearance deviations and the baseline radial clearance.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing will be apparent from the following more particular description of exemplary embodiments of the disclosure, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, with emphasis instead being placed upon illustrating the disclosed embodiments.

FIG. **1** is a flow diagram showing a method for adjusting the positioning of guide bearing pads to mitigate the effects of variations in the radial guide bearing clearance, in accordance with one embodiment of the present disclosure.

FIG. **2** is a perspective view of an exemplary guide bearing adjustment system with the gearbox cover removed for clarity depicting at least a shaft of a turbine, a guide bearing pad, and the radial clearance between the sidewall of the shaft and the guide bearing pad, in accordance with one embodiment of the present disclosure.

FIGS. **3**A-**3**B are perspective views of some embodiments of a guide bearing adjustment system including a chain and sprocket as the transmission between a prime mover and the adjustable guide bearings.

FIG. **4** is perspective view of an exemplary guide bearing adjustment system including a circular rack and pinion as the transmission between a prime mover and the adjustable guide bearings.

FIG. **5** is a perspective view of an exemplary guide bearing adjustment system including lever action and gears as the transmission between a prime mover and the adjustable guide bearings.

FIG. **6** is a perspective cross-sectional view of an exemplary guide bearing adjustment system comprising a wedge system as the transmission between a prime mover and the adjustable guide bearings.

FIG. **7** is a block diagram depicting a first embodiment of a system for adjusting the positioning of guide bearing pads to mitigate the effects of variations in the radial guide bearing clearance, in accordance with the present disclosure.

FIG. **8** is a block diagram illustrating a system that can incorporate the system for adjusting the positioning of guide bearing pads that is depicted in FIG. **7**, in accordance with one embodiment of the present disclosure.

FIG. **9** is a flowchart depicting possible signal paths of the distance signal.

DETAILED DESCRIPTION

The following detailed description of the preferred embodiments is presented only for illustrative and descriptive purposes and is not intended to be exhaustive or to limit the scope and spirit of the invention. The embodiments were selected and described to best explain the principles of the invention and its practical application. One of ordinary skill in the art will recognize that many variations can be made to the invention disclosed in this specification without departing from the scope and spirit of the invention.

Corresponding reference characters indicate corresponding parts throughout the several views. Although the drawings represent embodiments of various features and components according to the present disclosure, the drawings are not necessarily to scale and certain features may be exaggerated in order to better illustrate embodiments of the present disclosure, and such exemplifications are not to be construed as limiting the scope of the present disclosure in any manner.

References in the specification to "one embodiment", "an embodiment", "an exemplary embodiment", etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to affect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described.

Although specific terms are used in the following description for the sake of clarity, these terms are intended to refer only to the particular structure of the embodiment selected for illustration in the drawings, and are not intended to define or limit the scope of the disclosure.

The singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. Numerical values should be understood to include numerical values which are the same when reduced to the same number of significant figures and numerical values which differ from the stated value by less than the experimental error of conventional measurement technique of the type described in the present application to determine the value.

All ranges disclosed herein are inclusive of the recited endpoint and are independently combinable (for example, the range "from 2 grams to 10 grams" is inclusive of the endpoints, 2 grams and 10 grams, and all intermediate values.

As used herein, approximating language may be applied to modify any quantitative representation that may vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as "about" and "substantially," may not be limited to the precise values specified. The modifier "about" should also be considered as disclosing the range defined by the absolute values of the two endpoints. For example the expression "from about 2 to about 4" also discloses the range "from 2 to 4."

It should be noted that many of the terms used herein are relative terms. For example, the terms "upper" and "lower" are relative to each other in location, i.e. an upper component is located at a higher elevation than a lower component in a given orientation, but these terms can change if the device is flipped. The terms "inlet" and "outlet" are relative to a fluid flowing through them with respect to a given structure, e.g. a fluid flows through the inlet into the structure and flows through the outlet out of the structure. The terms "upstream" and "downstream" are relative to the direction in which a fluid flows through various components, i.e. the flow of fluids through an upstream component prior to flowing through the downstream component.

The terms "horizontal" and "vertical" are used to indicate direction relative to an absolute reference, i.e. ground level. However, these terms should not be construed to require structure to be absolutely parallel or absolutely perpendicular to each other. For example, a first vertical structure and a second vertical structure are not necessarily parallel to each other. The terms "top" and "bottom" or "base" are used to refer to locations/surfaces where the top is always higher than the bottom/base relative to an absolute reference, i.e. the surface of the Earth. The terms "upwards" and "downwards" are also relative to an absolute reference; an upwards flow is always against the gravity of the Earth.

The term "directly" when used to refer to two system components, such as valves or pumps, or other control devices, or sensors (e.g. temperature or pressure), means that the first component and the second component are connected without any intermediary component, such as valves or pumps, or other control devices, or sensors (e.g. temperature or pressure), at the interface of the two components.

Hydroelectric turbine assemblies tend to have hydrodynamic guide bearings disposed adjacent to the shaft, below and/or above the generator. A guide bearing may comprise multiple discrete guide bearing pads (or "shoes") configured to reduce friction, facilitate rotational shaft movement during operation, resist lateral forces during fault events, and to center the shaft in the shaft housing. The guide bearing pads are typically disposed annularly within a shaft housing, in which the guide bearing pads define a radial guide bearing clearance between the guide bearing pads and the shaft. A shaft seal may be disposed below and above the guide bearing pads to contain hydrodynamic fluid (typically oil or water). The fluid fills spaces between the shaft, shaft housing, and shaft seals, including the radial guide bearing clearance. Ideally, the shaft spins against a film of fluid annularly disposed between the guide bearing pads and the rotating shaft. This fluid film is generally highly pressurized by the relative motion of the shaft to the pads in order to resist normal and fault forces and to keep the shaft centered.

However, it has been determined that the width of the radial guide bearing clearance can differ significantly depending on the bearing system's ambient temperatures. That is, a "cold" shaft creates a wider clearance than a "hot" shaft that has thermally expanded to operating temperatures. The radial guide bearing clearance is set once during system commissioning. Manual measurement and adjustment of radial guide bearing clearances can be tedious and time consuming, and must be done while the machine is off-line.

To compensate, the equipment suppliers evaluate shaft thermal expansion and size the shaft to expand into an acceptable "hot" radial guide bearing clearance when the turbine is running consistently at normal operating conditions. Therefore, suppliers typically install a cold shaft between the discrete guide bearing pads. This results in a "cold" radial guide bearing clearance that is generally wider and less concentric (due to suboptimal flow conditions in the fluid film) than a "hot" radial guide clearance. After startup, the shaft gradually warms and eventually expands until the shaft temperature equalizes to operating temperatures. The thermally expanded shaft thereby defines a narrower, more concentric "hot" radial guide bearing clearance.

During the startup period when there is a greater radial clearance, the fluid's film pressure is not sufficient to resist the side forces that the discharged dam water exerts on the turbine. The variable side forces thereby rock the turbine and rotor along the shaft, which frequently results in potentially system-compromising vibrations, wear-inducing or damage-inducing direct contact between the shaft and guide bearing pads, and unnecessary alarms or trips. A trip deactivates the turbine once vibrations surpass a programmed threshold, whereas alarms merely warn of an aberrant system condition. To bring the system to operating conditions, equipment owners often override the alarms and automatic shutoff protocols.

It has been determined that for this reason, starting up a turbine can be perilous. Nearby operating personnel subject themselves to safety risks, and the turbine-generator assembly risks being damaged. In an extreme case, a lose-fitting shaft may allow the rotor assembly to contact the stator assembly and essentially destroy the rotor poles, stator core, and stator winding. Vibration may also weaken or cause fatigue failure in other internal generator components. When operators or installers elevate alarm and trip thresholds to prevent trips at startup, the operators or installers may not detect significant problems in time to deactivate the system and avoid catastrophic failure.

Accordingly, there is a long-felt and unresolved need to mitigate the problems caused by radial clearance variances during startup. Furthermore, the radial guide clearance occasionally changes abruptly during operation in response to an upset condition. An upset condition may result from hydraulic disturbances, electrical fault, applying the turbine brakes suddenly, the turbine runner encountering a large piece of debris, or some other unplanned operational event.

In accordance, with the methods, structures and computer program products that are described herein, the problem of shaft vibrations in rotating machines having hydrodynamic bearings is mitigated by a system configured to monitor the radial clearance between guide bearings, and the shaft about which the guide bearings are positioned, and to adjust a position of one or more guide bearing pads relative to the shaft while the rotating machine is active. An advantage of the exemplary system may be that the radial guide bearing clearance may be continuously monitored and adjusted in response to a thermally expanding shaft, thereby maintaining an optimal radial guide bearing clearance during startup and throughout operation of the rotating machine.

A further advantage of some embodiments of the system described in the present disclosure may be the protection against back driving that may otherwise result from upset conditions of the radial guide bearing clearance. Back driving occurs when the shaft assembly unexpectedly contacts a guide bearing pad. The contact force may be sufficient to drive the guide bearing pad and any linear adjustment bolt back (i.e. radially outward) from the shaft's center of rotation. The back driving force would render the static adjustment mechanisms disclosed in these prior patent applications and utility models non-functional. A back-driven guide bearing pad creates a large, uneven gap between the pad's back-driven shaft side and the shaft, which can quickly destabilize the shaft assembly and require immediate system shutdown.

The methods and systems of the present disclosure are now described in greater detail with reference to FIGS. **1**-**9**.

FIG. **1** is a flow diagram showing a method for adjusting the positioning of guide bearing pads **210**, **410**, **510**, **610**, **710** to mitigate the effects of variations in the radial guide bearing clearance, in accordance with one embodiment of the present disclosure. FIGS. **2**-**6** illustrate exemplary guide bearing adjustment systems **1000***a*, **1000***b*, **1000***c*, **1000***d*, **1000***e* that can be used in combination with the method described with reference to FIG. **1**. FIGS. **7** and **8** illustrates some embodiments of a control system **1100** for use with the structures and methods depicted in FIGS. **1**-**6**.

The flowchart and block diagrams in the Figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods, and computer program products according to various embodiments of the present invention. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of instructions, which comprises one or more executable instructions for implementing the specified logical function(s). In some alternative implementations, the functions noted in the blocks may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts or carry out combinations of special purpose hardware and computer instructions.

Referring to block **1** of FIG. **1**, in one embodiment, the method for maintaining a radial clearance between a variable guide bearing **293**, **493**, **593**, **693**, **793** and a shaft **220**, **420**, **520**, **620**, **720** of a turbine may begin with include measuring a baseline radial clearance between at least one guide bearing pad **210**, **410**, **510**, **610**, **710** and the shaft **220**, **420**, **520**, **620**, **720** of the turbine. The turbine may be a hydroelectric turbine. However, the methods, systems and structures of the present disclosure are not limited to only this example. The methods, structures and systems described herein are applicable to any turbine systems that employs guide bearings.

As used herein, the "radial clearance" is a dimension between an outermost shaft end **211** of the at least one bearing pad and an outermost perimeter of a shaft assembly (shaft **220**). The radial clearance is depicted in FIG. **2** by reference number **215**, in which the dimension for the radial clearance is identified by D. The radial clearance is identified by reference numbers **415**, **515**, **615**, **715** in FIGS. **3**A-**6**. The radial clearance in the systems described herein may be continually measured, and compared to the "baseline radial clearance". In some embodiments, the difference between the baseline radial clearance and the measured radial clearance provides the differential by which the variable guide bearing **293** may be adjusted to provide for an optimized clearance. The baseline radial clearance may take into account a mode of operation for the turbine. For example, the baseline clearance may be different for start up of the turbine, when the turbine is cold, when the turbine is hot and a combination of those factors. The baseline radial clearance may also take into account different operational considerations of the turbine, such as the hours that a turbine may have been in operation.

Referring to FIG. **7**, the baseline radial clearance **1102** may be stored in the memory **1101** of a control system **1100** for maintaining a radial clearance between a variable guide bearing and a shaft of a turbine. The control system **1100** may also be referred to as the controller that receives a distance signal from a sensor measuring the radial clearance and signals a pad adjuster **245**, **445**, **645**, **745** to traverse the at least one bearing, e.g., variable guide bearing **293**, **493**, **593**, **693**, **793** to compensate for the deviations in the radial clearance. In one embodiment, the control system **1110** may include at least one module of memory **1102** for storing baseline radial clearance values for a dimension between at least one guide bearing and the shaft of the turbine.

The baseline radial clearance values may be entered into the control system **1100** by an operator that interfaces with the control system **1110** over a user interface adapter **150**, as depicted in FIG. **8**. In this example, an operator of the turbine may enter values for the baseline radial clearance from at least one input device **152**, **153**, **156**. The at least one input device **152**, **154**, **156** may be any computing device, such as a desktop computer, mobile computer, laptop computer, tablet, smart phone and/or computer specific to the turbine.

The input devices **152**, **154**, **156** may be in connection with the user interface adapter **150** via a wireless connection, or the input devices **152**, **154**, **156** may be hard wired into electrical communication with the user interface adapter **150**.

The baseline radial clearance may be a value that is manually measured from the turbines during start up, or while the device is offline, and may also take into account measurements while the turbine is in operation.

In some other embodiments, the control system **1100** may employ machine learning to adjust the baseline radial clearance taking into account at least one of historical measurements for the radial clearance, real time measurements of the radial clearance and manufacturer suggested values for the radial clearance. Machine learning algorithms build a mathematical model based on sample data, known as "training data", in order to make predictions or decisions without being explicitly programmed to perform the task. In this case, the historical measurements may be employed with operation conditions to provide training data algorithms, which can in turn be employed to use real time data to update the baseline radial clearance.

Referring to FIG. **1**, the method may continue at block **2** with engaging a pad adjuster system to the at least one guide bearing **293**. The guide bearing pads **210** are preferably made of oil-resistant or water material in addition to being made of a material that has a low friction coefficient. In one embodiment, the at least one guide bearing **293** may include a bearing pad **210** of steel with tin white metal lining. The white metal lining can be a tin-based babbit. Tin-based babbitt is a material that contains more than 80% of tin alloy. The material may also contain lesser parts of antimony, lead and copper.

Some embodiments of the pad adjuster systems are depicted in FIGS. **2-6**. In each of the following described embodiments, the pad adjuster system may include a prime mover **230** in communication through a transmission to a pad adjuster **245**, **445**, **645** that is connected to at least one guide bearing pad **210**, **410**, **510**, **610**, **710** of the guide bearing **293**, **493**, **593**, **693**, **793**. The pad adjuster **245**, **445**, **645**, **745** can be actuated by a motive force from the prime mover **230**, which traverses the at least one guide bearing pad **210**, **410**, **510**, **610**, **710** in a direction to adjust a radial clearance. For example, the prime mover **230** may be a motor, such as a bidirectional motor that allows for the motor to turn in either direction, i.e., two opposing directions, while controlling the speed. In one example, when the motor of the prime mover **230** is moving in a first direction, the pad adjuster system may move the at least one guide bearing pad **210**, **410**, **510**, **610**, **710** to increase the radial clearance; and when the motor of the prime mover **230** is moving in a second direction (that is opposite the first direction) the pad adjuster system may move the at least one guide bearing pad **210**, **410**, **510**, **610**, **710** to decrease the radial clearance.

FIG. **2** is a perspective view of an exemplary guide bearing adjustment system **1000***a* with the gearbox cover removed for clarity. The exemplary guide bearing adjustment system **1000***a* may be disposed on a bearing support structure **202** comprising multiple ribs **203** engaging a support ring **207**. The support ring **207** is sometimes known as a "bracket." Traditionally, fasteners secured static guide bearing pads to the support ring **207**.

In the embodiment depicted in FIG. **2**, the pad adjuster **245**, being an adjustment bolt, extends through the support ring **207** to engage the guide bearing pad **210**. However, it is contemplated that a pad adjuster **245** need not necessarily pass through the support ring **207** in all embodiments. Both the ribs **203** and the support ring **207** may be disposed on a platform **201**.

A prime mover **230** engages a gearing system **241** represented by gearbox **242** in a non-collinear fashion relative to the length L of the pad adjuster **245**. More specifically, a motor of the prime mover **230** is connected to a driveshaft **236** having one or more driveshaft gears **238** disposed around the driveshaft **236**. The driveshaft gears **238** engages the active gear **246** of the gearing system **241** that is represented by the gearbox having reference number **242**. In this example, the transmission of the pad adjuster system includes at least one of the driveshaft **236**, the driveshaft gears **238** and the active gear **246** (which may be a worm gear **240**) of the gearing system **241**.

In the depicted embodiment, the pad adjuster's length L corresponds to the real or potential linear movement of the pad adjuster **245**. In some embodiments, by configuring the prime mover **230** to engage a gearing system **241** non-collinearly relative to the real or potential linear movement of the pad adjuster **245**, the exemplary guide bearing adjustment system **200** protects against unexpected back driving that could otherwise damage a bearing adjustment system, result in a loss of shaft guidance, or close the gap between rotating and stationary components. Without being bound by theory, the non-collinear engagement may provide sufficient counter-force to overcome back driving forces.

A prime mover assembly **234** engages a gearing system **241** represented by gearbox **242** in a non-linear fashion relative to the length L of the pad adjuster **245**. The prime mover assembly **234** may comprise a prime mover **230**, a drive shaft **236** engaged to the prime mover **230**, and one or more driveshaft gears **238** disposed around the driveshaft **236**. In FIG. **2**, the driveshaft gear **238** is a worm screw **235**. The driveshaft gear **238** engages the active gear **246** along a second plane **223** disposed tangentially to the circumference of the driveshaft gear **238**.

In the depicted embodiment, the length L of the pad adjuster **245** corresponds to the real or potential linear movement of the pad adjuster **245**. The length L of the pad adjuster **245** further separates a first end **243** of the pad adjuster **245** from a pad end **247** of the pad adjuster **245**. As depicted in FIG. **2**, the first end **243** of the pad adjuster **245** is the end of the pad adjuster **245** that is furthest from the guide bearing pad **210**, while the pad end **245** of the pad adjuster **245** is the closest end of the pad adjuster **245** to the back side **212** of the guide bearing pad **210**.

The length L of the pad adjuster **245** further defines a first plane **227**. The pad adjuster **245** has a thread that provides for rotation of the pad adjuster **245** around the length L (center of rotation C). The length L of the pad adjuster **245** extends along a horizontal direction in FIG. **2**. The first plane **227** is a horizontal plane in FIG. **2**. The second plane **223** is not collinear with the first plane **227**. In FIG. **2**, the second plane is a vertical plane than intersects the first plane **223** perpendicularly. It has been discovered that by configuring the prime mover assembly **234** to engage a gearing system **241** through a driveshaft gear **238** disposed on a second plane **227**, wherein the second plane **227** is not collinear with the first plane **223**, the exemplary guide bearing adjustment system **200** is thereby configured to protect against unexpected back driving that could otherwise damage a bearing adjustment system. For example, the pad adjuster **245** may be rotated about a horizontal axis parallel to the length of the pad adjuster **245**, while the driveshaft **236** engaged to the prime mover **230** is rotated about a vertical axis, the driveshaft gears **238** engaging the active gear **246**.

In one example of the depicted embodiment in FIG. **2**, the prime mover **230** engages a worm screw **235** (which provides the driveshaft gears **238**). The worm screw **235** tangentially engages a worm wheel **240** (which provides the active gear **246**) in the gearbox **242**. The worm wheel **240** is disposed around the pad adjuster **245**. When the prime mover **230** is activated, the prime mover **230** rotates the worm screw **235**. The worm screw **235** in turn rotates the worm wheel **240** around the worm wheel's center of rotation C. The worm wheel **240** in turn engages threads **244** on the pad adjuster **245** thereby transforming the worm wheel's circular movement into linear movement. The pad adjuster **245** may engage the back side **212** of the guide bearing pad **210** directly. However, in other exemplary embodiments, one or more elements may be disposed between the pad end **247** of the pad adjuster **245** and the back side **212** of the guide bearing pad **210**. For example, in the depicted embodiment, a spacer **253** encloses the pad end **247** and fasteners **248** engage the spacer **253** to the backside **212** of the guide bearing pad **210**. The spacer **253** may be a fastener interface plate or other device configured to engage the pad adjuster **245** to the guide bearing pad **210**. In other embodiments, the spacer **253** may be integrated into the guide bearing pad **210**.

In FIG. **2**, the guide bearing pad **210** together with the spacer **253** and fasteners **248** comprise the bearing pad assembly **213**. In other exemplary embodiments, the bearing pad assembly **213** may comprise a bearing pad **210** and a structure configured to engage the pad adjuster **245** to the guide bearing pad **210**.

Furthermore, in the depicted embodiment, the pad adjuster **245** is an adjustment bolt, but it will be understood that other devices configured to adjust the position of a guide bearing pad **210** along a radial plane defined by the center of rotation C of the shaft **220** are considered to be within the scope of this disclosure. Likewise, it will be understood that the prime mover **230** may comprise a motor, a hydraulic actuator, an electric stepper, or another device configured to actuate a gearing system **241**. Additionally, the gearing system's power transmission functionality can be provided instead by a combination of power transmission solutions, which includes, but is not limited to gears, racks, pinions, belts, pulleys, and chains. The protective anti-back-drive function can be substituted by a specialized coupling, such as the one disclosed in US. Pat. Pub. No. 2013/0206530, the entirety of which is incorporated herein by reference, or a locking mechanism that is engaged when the prime mover **230** is not moving, or a prime mover **230** being designed to provide continuous magnetic resistance to guide bearing forces.

FIGS. **3A-6** are alternative exemplary embodiments of systems for guide bearing adjustments **1000*b***, **1000*c***, **1000*d***, **1000*e*** including pad adjuster systems. In at least one example of the embodiment depicted in FIG. **2**, each guide bearing pad **210** includes its own pad adjuster system, which may include a pad adjuster **245** that is actuated by an individual prime mover assembly **230**, in which an individual transmission connects the individual prime mover assembly **230** to the pad adjuster **245**. In the embodiment depicted in FIG. **2**, the transmission may include at least one of the driveshaft **236**, the driveshaft gears **238** and the active gear **246** (which may be a worm gear **240**) of the gearing system **241**. In the embodiments depicted in FIGS. **3A-6**, the prime mover assembly does not engage each pad adjuster **445**, **645**, **745** for each guide bearing pad **210** individually. In the embodiments depicted in FIGS. **3A-6**, a transmission is provided that includes a linkage member **483**, **583**, **683**, **783** that can connect a single prime move assembly to more than one pad adjuster **445**, **645**, **745**. In these examples, the linkage member **483**, **583**, **683** can allow for fewer prime mover assemblies to actuate a plurality of variable guide bearing pads **210**, **410**, **510**, **610**, **710**. In certain exemplary embodiments, one prime mover assembly may be configured to move all guide bearing pads **210** through a linkage member **483**, **583**, **683**, **783**; and a gear system **441**, **474**, **541**, **641**, **649**, **741** that transmits the mechanical force from the linkage member **483**, **583**, **683**, **783** to the pad adjuster **445**, **645**, **745**.

FIGS. **3**A and **3**B depict a chain-driven embodiment of a system for guide bearing adjustments **1000*b*** in which the linkage member **483** comprises a chain **473** configured to transfer a motive force from the prime mover to a gearing system **441**. The chain **473** mechanically engages the prime mover. The chain **473** also mechanically engages multiple sprocket gears **474**, in which the chain **473** and the multiple sprocket gears **473** provides the gearing system **441**. The bearing pad adjustment system **1000*b*** can adjust the variable guide bearing pads **410** to adjust the radial clearance. The combination of the gearing system **441** and the chain **473** that provides the linkage member **483** provides the transmission that connects the prime mover and the pad adjuster **445** for moving the guide bearing pad **410** for adjusting the radial clearance. It is noted that the guide bearing pad identified by reference number **410** in FIG. **3**A is similar to the guide bearing pad identified by reference number **210** in FIG. **2**. Therefore, the description of the bearing pad identified by reference number **210** is suitable for describing the bearing pad identified by reference number **410**. The radial clearance is between the outer perimeter **471** of the shaft **420**, and the outermost surface **416** of the bearing pad **410**.

In the depicted exemplary embodiment, the gearing system **441** includes a sprocket gear **474** having teeth for engaging the chain **473**, as well as the threads on a worm wheel **440** engaged to the pad adjuster **445**. Each sprocket gear **474** engages a worm wheel **440**. The sprocket gear **474** transfers the motive force to the worm wheel **440**. The worm wheel **440** engages threads **444** on the pad adjuster **445** to transform the rotational movement of the worm wheel **440** into linear movement for the pad adjuster **445**. The pad adjuster **445** comprises a first end **443** distally disposed from a pad end **447**. The pad end **447** engages the guide bearing pad **410**. As depicted in FIGS. **3**A and **3**B, the first end **443** of the pad adjuster **445** is the end of the pad adjuster **445** that is furthest from the guide bearing d **410**, while the pad end **445** of the pad adjuster **445** is the closest end of the pad adjuster **445** to the back side **412** of the guide bearing pad **410**.

FIG. **4** depicts an exemplary bearing pad adjustment system **1000*c*** in which the linkage member **583** includes a circular rack **567** that is in threaded engagement to pinion gears **540**. The bearing pad adjustment system **1000*c*** can adjust the variable guide bearing pads **510** to adjust the radial clearance. The circular rack **567** and the pinion gears **540** can provide the transmission that transmits the motive force from the prime mover to the pad adjuster, in which the pad adjuster applies the motive force to the back surface **512** of the guide bearing pads **510**. The pinion gears **540** may be in threaded engagement with a pad adjuster (not depicted). It is noted that the guide bearing pad identified by reference number **510** in FIG. **4** is similar to the guide bearing pad identified by reference number **210** in FIG. **2**. Therefore, the description of the bearing pad identified by reference number **210** is suitable for describing the bearing pad identified by reference number **510**. The radial clearance is between the outer perimeter **571** of the shaft **520**, and the outermost surface **516** of the bearing pad **510**.

A prime mover, e.g., motor, engages the circular rack **567**. The circular rack **567** in turn engages multiple pinion gears **540** annularly arrayed around the shaft assembly **570**, wherein each pinion gear **540** engages a bearing adjuster configured to engage a guide bearing pad assembly **513**. The shaft assembly **570** may be the shaft of a hydroelectric turbine. The guide bearing pad assembly **513** is similar to the guide bearing pad assembly **213** that is depicted in FIG. **2**. The guide bearing pad assembly **513** may include a spacer **553** and fasteners to the guide bearing pad **510**.

In some embodiments, the prime mover rotates the circular rack **567**, and the circular rack **567** transfers the motive force to the pinion gear **540** and subsequently, the bearing adjuster (pad adjuster). The bearing adjuster engages the guide bearing assembly **513**, and thereby adjusts the position of the guide bearing pads **510** uniformly along radial lines extending from the shaft's center of rotation C. A seal **519** may be disposed adjacent guide bearing pads to prevent lubricant, such as water or oil from leaking out from the gap **515**.

FIG. **5** depicts an exemplary bearing adjustment system **1000***d* in which the linkage member **683** includes a lever action **678**. The bearing pad adjustment system **1000***d* can adjust the variable guide bearing pads **610** to adjust the radial clearance. The lever action **678** may include an arm **679** that is in contact with a gearing system **641** that includes a worm wheel **649** and a pinion gear **640** that corresponds to each of the variable guide bearing pads **610**. The arm **679** of the level action **678** is in direct communication with the worm wheel **649**. The worm wheel **649** may be in threaded engagement with the pinion gear **640**. The pinion gear **640** is engaged to the pad adjuster **645**. The bearing pad adjustment system **1000***d* can adjust the variable guide bearing pads **610** to adjust the radial clearance. The lever action **678** may further include lever links **677**. The lever links **677** connect each of the arms **679**. The lever links **677** and the arms **679** of the lever action **678**, in connection with the worm wheel **649** and the pinion gear **640**, can provide the transmission that transmits the motive for generated by the prime mover to the pad adjuster **645**, in which the pad adjuster **645** is connected to the variable guide bearing pads **610**. The pinion gears **640** may be in threaded engagement with a pad adjuster (not depicted). It is noted that the guide bearing pad identified by reference number **610** in FIG. **5** is similar to the guide bearing pad identified by reference number **210** in FIG. **2**. Therefore, the description of the bearing pad identified by reference number **210** is suitable for describing the bearing pad identified by reference number **610**. The radial clearance is between the outer perimeter **671** of the shaft **620**, and the outermost surface **616** of the bearing pad **610**.

A prime mover, e.g., motor, engages the lever action **678**. The lever action **678** in turn engages multiple pinion gears **640** annularly arrayed around the shaft assembly **670**, wherein each pinion gear **640** engages a bearing adjuster configured to engage a guide bearing pad assembly **613**. The shaft assembly **670** may be the shaft of a hydroelectric turbine. The guide bearing pad assembly **613** is similar to the guide bearing pad assembly **213** that is depicted in FIG. **2**. The guide bearing pad assembly **613** may include a spacer **653** and fasteners to the guide bearing pad **610**.

In some embodiments, the prime mover rotates the lever action **678**, and the lever action **678** transfers the motive force to the pinion gear **640** and subsequently, the bearing adjuster (pad adjuster **645**). The bearing adjuster **645**, engaging the guide bearing assembly **613**, thereby adjusts the position of the guide bearing pads **610** uniformly along radial lines extending from the shaft's center of rotation C. A seal **619** may be disposed adjacent guide bearing pads to prevent lubricant, such as water or oil from leaking out from the gap **615**.

In some embodiments, a prime mover engages the lever action **678**. In other exemplary embodiments, the lever action **678** can be configured to disengage the worm wheel **649** when adjustment is not desired.

FIG. **6** depicts another exemplary bearing adjustment system **1000***e* in which the linkage member **783** includes a wedge system **789** that relies on friction around the entire circumference of the back side **712** of the guide bearing pads **710** to resist back-driving at any one or several guide bearing pads **710**. In the embodiment that is depicted in FIG. **6**, the transmission of the pad adjuster system is the wedge system **789**. The bearing pad adjustment system **1000***e* can adjust the variable guide bearing pads **710** to adjust the radial clearance. It is noted that the guide bearing pad identified by reference number **710** in FIG. **6** is similar to the guide bearing pad identified by reference number **210** in FIG. **2**. Therefore, the description of the bearing pad identified by reference number **210** is suitable for describing the bearing pad identified by reference number **710**. The guide bearing pad **710** is a component of a guide bearing pad assembly **713**. The guide bearing pad assembly **713** is similar to the guide bearing pad assembly **213** that is depicted in FIG. **2**. The guide bearing pad assembly **713** may include a spacer **753** and fasteners to the guide bearing pad **610**. The radial clearance is between the outer perimeter **771** of the shaft **720**, and the outermost surface **716** of the guide bearing pad **710**.

A prime mover, e.g., motor, engages the lever action **778**. The lever action **778** in turn engages the back surface **712** of the guide bearing pads **710** annularly arrayed around the shaft assembly **770**. More specifically, a tapered portion of the wedge system **789** is inserted between the spacer **753** that is connected to the back surface **712** of the guide bearing pads **710** and the pad end **247** of the pad adjuster **245**. The greater dimension of the tapered portion of the wedge system **789** being slid between the pad end **747** of the pad adjuster **745** and the spacer **753** that is connected to the back surface **712** of the guide bearing pads **710** the greater distance that the guide bearing pads **710** are moved towards the outside perimeter **716** of the shaft **720**. The prime mover rotates the lever action **778**, and the lever action **778** transfers the motive force to the guide bearing pads **710**. It is noted wedge system **789** may actuate multiple guide bearing pads **710** simultaneously. The wedge system **789** that is positioned between the bearing adjuster **745** and the spacer **753** connected to the back surface **712** of the guide bearing pads **710** of the guide bearing assembly **613**, thereby adjusts the position of the guide bearing pads **710** uniformly along radial lines extending from the shaft's center of rotation C.

A seal **719** may be disposed adjacent guide bearing pads to prevent lubricant, such as water or oil from leaking out from the gap **715**.

Referring back to FIG. **1**, the method may further include measuring radial clearance deviations between the at least one guide bearing pad **210**, **410**, **510**, **610**, **710** and the shaft **220**, **420**, **520**, **620**, **720** of the turbine at block **3**. The radial clearance deviations may be measured at any time with respect to the operation and non-operation of the turbine. For example, cold measurements may be made when the turbine is not in operation, and hot measurements may be made when the turbine is functioning.

In some embodiments, a proximity sensor may take measurements of the radial clearance. Those measurements may be employed to determine a deviation from, i.e., difference from, the radial clearance from the baseline radial clearance that is set at block **1** of the method illustrated by FIG. **1**. The term, "proximity sensor" can be used to refer to different technologies having slightly different names, but all being sensors that result in a signal (digital, analog or mechanical) that is meant to indicate a distance, or proximity. One embodiment of a proximity sensor that is suitable for the methods, structures and systems of the present disclosure is identified by reference number **205** in FIG. **2**. In some embodiments, on the guide bearing pad side **216**, a sensor end of the proximity sensor **205** is disposed within the guide bearing adjustment system, as depicted in FIG. **2**. Any such substitutions are considered to be within the scope of this disclosure. In other exemplary embodiments, the proximity sensor may be omitted in favor of precise position feedback signals generated directly from the prime mover **230**.

By way of example, the proximity sensor **205** may be disposed within the guide bearing pad **210** and may have a sensor end facing the shaft assembly **270**. However, in other exemplary embodiments, the proximity sensor **205** may be disposed on the guide bearing pad **210** or above, below, or adjacent to the guide bearing pad **210**. The proximity sensor **205** is configured to measure the distance D of the radial clearance **215** between the outermost surface **216** of the bearing pad assembly **213** and the outermost perimeter **271** of the shaft assembly **270**. The radial clearance **215** is typically the space between the guide bearing pad's shaft side **211** and the shaft **220**. This radial clearance **215** is configured to be filled with lubricant **217**, such as water or oil. That is, in FIG. **2**, the outermost surface **216** of the bearing pad assembly **213** is the shaft side **211** of the guide bearing **210** and the outermost perimeter **271** of the shaft assembly **270** is the perimeter of the shaft **220**.

Accordingly, the radial clearance **215** is the distance D between the shaft side **211** and the shaft **220**. However, in other exemplary embodiments, the shaft assembly **270** may further comprise one or more sleeves disposed around the shaft **220**. When a sleeve or other object is disposed between the shaft side **211** of the guide bearing pad **210** and the shaft **220**, the radial clearance will be understood to be the distance D between the outermost surface **216** of the bearing pad assembly **213** and the outermost perimeter **271** of the shaft assembly **270**.

It is noted that the description of the proximity sensor identified by reference number **205** for the bearing adjustment system **1000***a* that is in FIG. **2** is equally applicable for providing the description of the proximity sensor that can be employed for the bearing adjustment systems **1000***b*, **1000***c*, **1000***d*, **1000** that are depicted in FIGS. **3A-6**. In each of the embodiments that are depicted in FIGS. **3A-6**, a proximity sensor may be integrated into the guide bearing pad assembly **413**, **513**, **613**, **713** similar to how the proximity sensor is integrated into the guide bearing pad assembly **213** that is depicted in FIG. **2**. More specifically, a proximity sensor may be disposed on the guide bearing pad **410**, **510**, **610**, **710** or above, below, or adjacent to the guide bearing pad **410**, **510**, **610**, **710**. The proximity sensor is configured to measure the distance of the radial clearance **415**, **515**, **616**, **715** between the outermost surface **416**, **516**, **616**, **716** of the bearing pad assembly **413**, **513**, **613**, **713** and the outermost perimeter **471**, **571**, **671**, **771** of the shaft assembly **470**, **570**, **670**, **770**.

In some embodiments, the proximity sensor **205** is an inductive eddy current sensor. Inductive "eddy current" sensors are designed to output an analog voltage that is proportional to the distance between the sensor face and an electrically conductive 'target', e.g., the outermost perimeter **271** of the shaft assembly **270**. In operation the driver excites a wire wound coil in the probe with an RF signal. In one example, the RF signal is approximately 1 MHz. The coil in the probe generates an oscillating electromagnetic field. Any electrically conductive material engaging the field will have "eddy current" induced in its surface. The eddy current produces its own electromagnetic field. The interaction between the coil field and eddy current field produces an impedance change in the coil, the magnitude which is based on the distance between the two fields, or between the probe and the target surface. The driver monitors the impedance of the coil and outputs a linear analog voltage proportional to the distance between the probe and the target surface.

Referring to FIG. **1**, the method may continue with block **4** that further calculating a difference between the radial clearance deviations and the baseline radial clearance. In some embodiments, the calculation of the difference between the radial clearance deviations and the baseline radial clearance is provided by a control system **1100**, which can include a corrective radial clearance analyzer **1104**. FIGS. **7** and **8** depict one embodiment of a control system **1100** for adjusting the positioning of guide bearing pads **210**, **410**, **510**, **610**, **710** to mitigate the effects of variations in the radial guide bearing clearance. The control system **1100** may also be referred to as a controller.

The control system **1100** is in communication with the pad adjuster systems that have been described above with reference to FIGS. **2-6**. For example, the control systems **1110** may be in communication either by wireless communication or by hard wired communication with the prime mover, such as the prime mover identified by reference number **230** in FIG. **2**. For example, the control system **1100** may include at least one signal generator **1106** in communication with the pad adjuster system that traverses the at least one guide bearing pad **210**, **410**, **510**, **610**, **710** in a direction to adjust the radial clearance. In one embodiment, the at least one signal generator **1106** is in communication with the prime mover **230**.

In some embodiments, the control system **1100** may include a receiver **1103** for receiving measured radial clearance deviations between at least one guide bearing pad **210**, **410**, **510**, **610**, **710** and the shaft **270**, of the turbine.

In some embodiments, the control system **1100** may further include a corrective radial clearance analyzer **1104** that employs a hardware processor **1105** for performing a set of instructions for comparing the measured radial clearance deviations to the baseline radial clearance values in providing a corrective radial clearance dimension. As employed herein, the term "hardware processor subsystem" or "hardware processor" can refer to a processor, memory, software or combinations thereof that cooperate to perform one or more specific tasks. In useful embodiments, the hardware processor subsystem can include one or more data processing elements (e.g., logic circuits, processing circuits, instruction execution devices, etc.). The one or more data processing elements can be included in a central processing unit, a graphics processing unit, and/or a separate processor- or computing element-based controller (e.g., logic gates, etc.). The hardware processor subsystem can include one or more on-board memories (e.g., caches, dedicated memory arrays, read only memory, etc.). In some embodiments, the hardware processor subsystem can include one or more memories that can be on or off board or that can be dedicated for use by the hardware processor subsystem (e.g., ROM, RAM, basic input/output system (BIOS), etc.).

More specifically, the control system **1110** receives data measured on the radial clearance from the proximity sensor **205**, which can measured the radial clearance when the turbine is hot or cold, and/or when the turbine is offline or running, etc. The control system **1110** then employs the corrective radial clearance analyzer **1104** to compare the data measured on the radial clearance from the proximity sensor **205** to the baseline radial clearance that was previously determined in step **1** of the method depicted in FIG. **1**. The baseline radial clearance values may be stored in the memory **1101** of the control system **1100**, which can be provided in a module for baseline radial clearance **1102**. In some embodiments, the corrective radial clearance analyzer **1104** determines if the difference between the baseline radial clearance and the measured radial clearance is a deviation that is significant enough to be a radial clearance deviation from which the system of variable guide bearing may benefit from a correction in the radial clearance actuated by the pad adjuster system. To determine if correction is suitable, the corrective radial analyzer may employ a number of rules that are actuated by the hardware processor **1105** in calculating a solution to radial clearance deviations.

Each of the components for the control system **1110** that are depicted in FIG. **7** may be interconnected via a system bus **102**.

Any of the systems or machines (e.g., devices) shown in FIG. **7** may be, include, or otherwise be implemented in a special-purpose (e.g., specialized or otherwise non-generic) computer that has been modified (e.g., configured or programmed by software, such as one or more software modules of an application, operating system, firmware, middleware, or other program) to perform one or more of the functions described herein for that system or machine. For example, a special-purpose computer system able to implement any one or more of the methodologies described herein is discussed above with respect to FIGS. **1-6**, and such a special-purpose computer may, accordingly, be a means for performing any one or more of the methodologies discussed herein. Within the technical field of such special-purpose computers, a special-purpose computer that has been modified by the structures discussed herein to perform the functions discussed herein is technically improved compared to other special-purpose computers that lack the structures discussed herein or are otherwise unable to perform the functions discussed herein. Accordingly, a special-purpose machine configured according to the systems and methods discussed herein provides an improvement to the technology of similar special-purpose machines.

The control system **1100** may be integrated into the processing system **1200** depicted in FIG. **8**. The processing system **1200** includes at least one processor (CPU) **104** operatively coupled to other components via a system bus **102**. A cache **106**, a Read Only Memory (ROM) **108**, a Random Access Memory (RAM) **110**, an input/output (I/O) adapter **120**, a sound adapter **130**, a network adapter **140**, a user interface adapter **150**, and a display adapter **160**, are operatively coupled to the system bus **102**. The bus **102** interconnects a plurality of components has will be described herein.

The processing system **1200** depicted in FIG. **8**, may further include a first storage device **122** and a second storage device **124** are operatively coupled to system bus **102** by the/O adapter **120**. The storage devices **122** and **124** can be any of a disk storage device (e.g., a magnetic or optical disk storage device), a solid state magnetic device, and so forth. The storage devices **122** and **124** can be the same type of storage device or different types of storage devices.

A speaker **132** is operatively coupled to system bus **102** by the sound adapter **130**. A transceiver **142** is operatively coupled to system bus **102** by network adapter **140**. A display device **162** is operatively coupled to system bus **102** by display adapter **160**.

A first user input device **152**, a second user input device **154**, and a third user input device **156** are operatively coupled to system bus **102** by user interface adapter **150**. The user input devices **152**, **154**, and **156** can be any of a keyboard, a mouse, a keypad, an image capture device, a motion sensing device, a microphone, a device incorporating the functionality of at least two of the preceding devices, and so forth. Of course, other types of input devices can also be used, while maintaining the spirit of the present invention. The user input devices **152**, **154**, and **156** can be the same type of user input device or different types of user input devices. The user input devices **152**, **154**, and **156** are used to input and output information to and from the processing system **1200**.

Of course, the processing system **1200** may also include other elements (not shown), as readily contemplated by one of skill in the art, as well as omit certain elements. For example, various other input devices and/or output devices can be included in processing system **400**, depending upon the particular implementation of the same, as readily understood by one of ordinary skill in the art. For example, various types of wireless and/or wired input and/or output devices can be used. Moreover, additional processors, controllers, memories, and so forth, in various configurations can also be utilized as readily appreciated by one of ordinary skill in the art. These and other variations of the processing system **1200** are readily contemplated by one of ordinary skill in the art given the teachings of the present invention provided herein.

Referring to block **5** of FIG. **1**, in some embodiments, the method includes actuating the prime mover to adjust the at least one guide bearing to compensate for the difference between the radial clearance deviations and the baseline radial clearance.

FIG. **9** is a flowchart depicting possible signal paths of the distance signal **355**, which is measured by the proximity sensor **205** in measuring the radial clearance. In operation, the proximity sensor **205** measures the distance D of the radial clearance **215**, **415**, **515**, **615**, **715** to generate a distance signal **355**. The proximity sensor **305** then transmits the distance signal **355** to the control system **1100** that is configured to analyze the distance signal **355**. The control system **1100** may take a variety of forms physically, and may include by way of example, an integrated power and signal device, or separate power and signal processing devices connected together. The control system **1100** may be digital or analog, and controlled by programmable logic controller ("PLC") logic or relay logic. In an exemplary embodiment, the control system **1100** includes a corrective radial clearance analyzer **1104** that compares the value of the distance signal **355** to a programed range **357**. The programed range **357** may include the values stored within the module for baseline radial clearance that can be stored in the memory **43** of the control system **1100**. The control system **1100** can then send an adjustment signal **362** to the prime mover **230** if the distance signal **355** differs (e.g. is not an element in) from the programed range **357**. In one embodiment, if the distance signal **355** exceeds the programed range **357**, the adjustment signal **362** directs the guide bearing pad **210**, **410**, **510**, **610**, **710** toward the shaft **220**, **420**, **520**, **620**, **720**. In one embodiment, if the distance signal **355** does not exceed the programed range **357**, the adjustment signal **362** withdraws the guide bearing pad **210**, **410**, **510**, **610**, **710** from the shaft **220**, **420**, **520**, **620**, **720**. In certain exemplary embodiments, the pad adjuster **245**, **445**, **645**, **745** is configured to move the guide bearing pad **210**, **410**, **510**, **610**, **710** along a radial plane defined by the center of rotation C of the shaft **220**, **420**, **520**, **620**, **720** in response to the adjustment signal **362**. In other exemplary embodiments, the pad adjuster **245**, **445**, **645**, **745** may adjust the pitch of the guide bearing pad **220**, **420**, **520**, **620**, **720** in response to the adjustment signal **362**. Components of the exemplary guide bearing adjustment system are desirably made of oil-resistant materials.

In an exemplary embodiment, the prime mover **230** provides a redundant position signal to the control system **1100** to confirm the position of the radial guide bearing pad **210**, **410**, **510**, **610**, **710**.

The present invention may be a system, a method, and/or a computer program product at any possible technical detail level of integration. The computer program product can provide a method for maintaining a radial clearance between a variable guide bearing and a shaft of a turbine. The computer program product may include a computer readable storage medium (or media) having computer readable program instructions thereon for causing a processor to carry out aspects of the present invention. For example, the present disclosure provides a computer program product comprising a non-transitory computer readable storage medium having computer readable program code embodied therein. The computer readable program code can provide the steps of measuring a baseline radial clearance between at least one guide bearing and the shaft of the turbine. A pad adjuster may be engaged to the at least one guide bearing. The pad adjuster may include a prime mover in communication to the at least one guide bearing through a transmission, wherein the pad adjuster actuated by a motive force from the prime mover traverses that at least one guide bearing in a direction to adjust a radial clearance. The method may further include measuring radial clearance deviations between the at least one guide bearing and the shaft of the turbine, and calculating a difference between the radial clearance deviations and the baseline radial clearance. In some embodiments, the method includes actuating the prime mover to adjust the at least one guide bearing to compensate for the difference between the radial clearance deviations and the baseline radial clearance.

The computer readable storage medium can be a tangible device that can retain and store instructions for use by an instruction execution device. The computer readable storage medium may be, for example, but is not limited to, an electronic storage device, a magnetic storage device, an optical storage device, an electromagnetic storage device, a semiconductor storage device, or any suitable combination of the foregoing. A non-exhaustive list of more specific examples of the computer readable storage medium includes the following: a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), a static random access memory (SRAM), a portable compact disc read-only memory (CD-ROM), a digital versatile disk (DVD), a memory stick, a floppy disk, a mechanically encoded device such as punch-cards or raised structures in a groove having instructions recorded thereon, and any suitable combination of the foregoing. A computer readable storage medium, as used herein, is not to be construed as being transitory signals per se, such as radio waves or other freely propagating electromagnetic waves, electromagnetic waves propagating through a waveguide or other transmission media (e.g., light pulses passing through a fiber-optic cable), or electrical signals transmitted through a wire.

Computer readable program instructions described herein can be downloaded to respective computing/processing devices from a computer readable storage medium or to an external computer or external storage device via a network, for example, the Internet, a local area network, a wide area network and/or a wireless network. The network may comprise copper transmission cables, optical transmission fibers, wireless transmission, routers, firewalls, switches, gateway computers and/or edge servers. A network adapter card or network interface in each computing/processing device receives computer readable program instructions from the network and forwards the computer readable program instructions for storage in a computer readable storage medium within the respective computing/processing device.

Computer readable program instructions for carrying out operations of the present invention may be assembler instructions, instruction-set-architecture (ISA) instructions, machine instructions, machine dependent instructions, microcode, firmware instructions, state-setting data, or either source code or object code written in any combination of one or more programming languages, including an object oriented programming language such as SMALLTALK, C++ or the like, and conventional procedural programming languages, such as the "C" programming language or similar programming languages. The computer readable program instructions may execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider). In some embodiments, electronic circuitry including, for example, programmable logic circuitry, field-programmable gate arrays (FPGA), or programmable logic arrays (PLA) may execute the computer readable program instructions by utilizing state information of the computer readable program instructions to personalize the electronic circuitry, in order to perform aspects of the present invention.

Aspects of the present invention are described herein with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems), and computer program products according to embodiments of the invention. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer readable program instructions.

These computer readable program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks. These computer readable program instructions may also be stored in a computer readable storage medium that can direct a computer, a programmable data processing apparatus, and/or other devices to function in a particular manner, such that the computer readable storage medium having instructions stored therein comprises an article of manufacture including instructions which implement aspects of the function/act specified in the flowchart and/or block diagram block or blocks.

The computer readable program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other device to cause a series of operational steps to be performed on the computer, other programmable apparatus or other device to produce a computer implemented process, such that the instructions which execute on the computer, other programmable apparatus, or other device implement the functions/acts specified in the flowchart and/or block diagram block or blocks.

Having described preferred embodiments of a variable guide bearing (which are intended to be illustrative and not limiting), it is noted that modifications and variations can be made by persons skilled in the art in light of the above teachings. It is therefore to be understood that changes may be made in the particular embodiments disclosed which are within the scope of the invention as outlined by the appended claims. Having thus described aspects of the invention, with the details and particularity required by the patent laws, what is claimed and desired protected by Letters Patent is set forth in the appended claims.

What is claimed is:

1. A method for maintaining a radial clearance between a variable guide bearing and a shaft of a turbine comprising:

measuring, a baseline radial clearance between the variable guide bearing and the shaft of the turbine;

engaging a pad adjuster system to the variable guide bearing, the pad adjuster system includes a prime mover in communication to the variable guide bearing through a transmission, wherein the pad adjuster system is actuated by a motive force from the prime mover traversing the variable guide bearing in a direction to adjust the radial clearance, and wherein the pad adjuster system includes a threaded pad adjuster in contact with a back surface of the variable guide bearing, and an active gear in communication with the threaded pad adjuster in a non-collinear fashion relative to a length of the pad adjuster;

measuring radial clearance deviations between the variable guide bearing and the shaft of the turbine;

calculating a difference between the radial clearance deviations and the baseline radial clearance; and

actuating the prime mover to adjust the variable guide bearing to compensate for the difference between the radial clearance deviations and the baseline radial, clearance.

2. The method of claim **1**, wherein the method is a computer implemented method.

3. The method of, claim **1**, wherein the active gear is a worm gear.

4. The method of claim **3**, wherein the worm gear is in threaded engagement to a driveshaft gear actuated by the prime mover through a drive shaft.

5. The method of claim **1**, wherein the active gear is driven by a chain actuated by the prime mover, the chain, connecting a plurality of pad adjusters to a plurality of guide bearings.

6. The method of claim **1**, wherein the active gear is driven by an arm connected to a linkage actuated by the prime mover, the linkage connecting a plurality of pad adjusters to a plurality of variable guide bearings.

7. The method of claim **1**, wherein the prime mover is configured to provide a redundant position signal to a control system actuating the prime mover to confirm a position of the variable guide bearing.

8. A non-transitory article of manufacture tangibly embodying a computer readable program which when executed causes a computer to perform the method of claim **1**.

9. A guide bearing system comprising:

a pad adjuster system including a pad adjuster and a prime mover assembly configured to produce a motive force to traverse a bearing in a direction to adjust a radial clearance, wherein the radial clearance is a dimension between an outermost shaft end of a bearing pad and an outermost perimeter of a shaft assembly, the pad adjuster system further comprising a gearing system, the pad adjuster engaging the gearing system, wherein the pad adjuster has a first end and a pad end distally separated from the first end by a length, wherein the length defines a first plane, and wherein the pad end engages a bearing pad assembly including the bearing, the bearing pad assembly comprising the bearing pad having an outermost shaft end, the prime mover assembly engaging the gearing system on a second plane, wherein the second plane is not coextensive with the first plane;

a sensor for measuring deviations in the radial clearance; and

a control system configured to receive a distance signal from the sensor measuring the radial clearance and configured to signal the pad adjuster to traverse the bearing to compensate for said deviations in the radial clearance.

10. The guide bearing system of claim **9**, wherein the first plane is a horizontal plane and wherein the second plane is tangential to the horizontal plane.

11. The guide bearing system of claim **9**, wherein the bearing pad assembly further comprises a spacer engaging a back side of the hearing pad, and wherein the spacer encompasses the pad end of the pad adjuster.

12. The guide bearing system of claim **9**, wherein the pad adjuster is configured to move the bearing pad along a radial plane defined by a center of rotation of the shaft assembly, wherein the radial plane is coextensive with, the first plane.

13. The guide bearing system of claim **9**, wherein the gearing system includes a worm screw engaging a worm wheel, wherein the prime mover assembly is configured to transfer the motive force to the gearing system, wherein the pad adjuster engages the gearing system, wherein the bearing pad assembly comprises the bearing pad having a shaft side distally disposed from a back side, wherein the pad end of the pad adjuster engages the bearing pad assembly, and wherein a proximity sensor is configured to generate the distance signal comprising a distance of the radial clearance.

14. The guide bearing system of claim **13**, further comprising a mechanical transmission assembly disposed between the prime mover and the gearing system and engaging the prime mover and the gearing system, wherein the mechanical transmission assembly is configured to transfer the motive force from the prime mover to the gearing system.

15. The guide bearing system of claim **14**, wherein the mechanical transmission assembly is selected from the group consisting of a chain and sprockets, a circular rack and pinion gears, and a lever action and gears.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 10,961,977 B2
APPLICATION NO. : 16/664153
DATED : March 30, 2021
INVENTOR(S) : Sarmad Elahi et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims

In Column 21, Line 39, in Claim 1, delete "measuring," and insert -- measuring --.

In Column 21, Line 59, in Claim 1, delete "radial," and insert -- radial --.

In Column 21, Line 63, in Claim 3, delete "of," and insert -- of --.

In Column 21, Line 67, in Claim 4, delete "drive shaft." and insert -- driveshaft. --.

In Column 22, Line 2, in Claim 5, delete "chain," and insert -- chain --.

In Column 22, Line 53, in Claim 12, delete "with," and insert -- with --.

Signed and Sealed this
Thirteenth Day of June, 2023

Katherine Kelly Vidal

Katherine Kelly Vidal
Director of the United States Patent and Trademark Office